AD-A116 672 RAND CORP SANTA MONICA CA F/G 15/5
MULTINATIONAL COPRODUCTION OF MILITARY AEROSPACE SYSTEMS.(U)
OCT 81 M RICH, W STANLEY, J BIRKLER, M HESSE F49620-82-C-0018
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R-2861-AF

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Michael Rich, William Stanley,
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A Project AIR FORCE report
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Rand
SANTA MONICA, CA. 90406

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-2861-AF	2. GOVT ACCESSION NO. AD-A116672	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Multinational Coproduction of Military Aerospace Systems		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael Rich, William Stanley, John Birkler, Michael Hesse		8. CONTRACT OR GRANT NUMBER(s) F49620-82-C-0018
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Rand Corporation 1700 Main Street Santa Monica, CA. 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Requirements, Programs & Studies Group (AF/RDQM) Ofc, DCS/R&D and Acquisition Hq USAF, Washington, DC 20330		12. REPORT DATE October 1981
		13. NUMBER OF PAGES 147
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

No Restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Armed Forces Procurement
Military Aircraft
Europe

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See Reverse Side

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Assesses cost and schedule implications of acquiring weapon systems using multinational coproduction by examining experiences accumulated in a large and diverse set of aerospace development and production programs. Describes and, where possible, quantifies marked U.S. and European differences in such areas as production scale, workforce policies, schedule philosophy, and manufacturing methods that are a key to understanding the special consequences of international involvement in U.S. weapons production. Discusses implications of U.S. and European differences for collaborative production programs. Examines in detail the cost and schedule implications of coproduction in the F-16 fighter aircraft program, one of the most ambitious collaborative efforts ever attempted by the U.S. Concludes with findings and policy-related observations, some of which are specific to the F-16 program, and others which address more general issues associated with multinational coproduction.

PREFACE

As the scale and scope of multinational participation in U.S. military acquisition programs have grown, so has the need to understand the implications and special difficulties of collaborative programs. This report deals with coproduction, the most common form of multinational participation. It was sponsored by the Deputy Chief of Staff, Research, Development and Acquisition, Headquarters, U.S. Air Force, and examines the probable cost and schedule consequences of various forms of multinational coproduction. In particular, it analyzes the F-16 program, the most ambitious U.S. coproduction program to date.

This research, which concluded in the summer of 1981, was conducted under the Project AIR FORCE Resource Management Program study entitled "USAF Participation in Co-national Acquisition Programs."

A

SUMMARY

The United States and its European allies are increasingly considering multinational collaboration as a means for acquiring weapon systems, but there is still considerable debate and misunderstanding about its implications, advantages, and disadvantages. Many issues related to collaboration, particularly cost implications, are generally debated without the benefit of much quantitative information. Important questions remain about the planning and execution of collaborative programs in the contemporary acquisition environment and what one might reasonably expect in regard to program outcomes.

Coproduction, one of the most common forms of collaboration, is defined in this study to include programs that feature international collaboration during the production phase of a major weapon system. Increasingly, these arrangements include European involvement in the production of equipment for U.S. forces, a rare occurrence in the past and a development that sharpens the interest of the participating U.S. military services in program outcomes. Even proponents would agree that coproduction is not uniformly advantageous to the U.S. Air Force. It is therefore important to understand the implications of using this acquisition strategy, particularly because decisions to undertake multinational ventures have in some cases been made outside the usual weapons acquisition decisionmaking apparatus, affording the military services little time for assessing their merits or consequences.

This study has the dual objective of improving understanding of the implications of multinational coproduction arrangements, especially with respect to program costs and schedules, and identifying various ways to maximize their advantages while avoiding their pitfalls. Some of the more important questions addressed include: Does coproduction impose a consistent cost penalty on the United States? Do collaborative programs take longer and experience more schedule slippage than comparable national programs? Are European collaborative programs a good guide for predicting the outcomes of joint U.S.-European programs?

We pursued the aforementioned objectives in the context of the production of aerospace systems and from predominantly, although not always, a U.S. Air Force perspective. The research findings are interpreted primarily in the context of their relevance for future U.S.-European collaborative ventures. We discuss issues associated with codevelopment and weapons standardization, but only in regard to their implications for coproduction programs.

A large and diverse set of aerospace development and production programs made up our data base, including U.S. and European collaborative and national ventures, with the national programs serving as a baseline against which we could compare the characteristics of collaborative programs. To understand the consequences and pitfalls of U.S.-European weapons production collaboration, we identified differences in acquisition approach of the United States and the European nations and the reasons for those differences. We then assessed the implications of those national differences for U.S.-European production collaboration as well as other considerations brought about by the act of collaboration that can influence the structure and outcomes of programs. Finally, exploiting a proprietary cost data base, we examined the cost and schedule implications of the multinational coproduction of the F-16 fighter aircraft, the largest and most complex U.S. coproduction program to date.

Because collaboration is more common among European nations than between European nations and the United States, purely European collaborative program experiences have

shaped many of the expectations about collaborative program outcomes. Our research suggests that such perceptions are less relevant than earlier believed; specifically,

Collaborative programs involving the United States as a producer warrant considerably more optimism about outcomes than all-European collaborative ventures. Outcomes of purely European programs appear to be shaped at least as much by generic features of the European acquisition setting as by collaborative factors. Involvement by the United States can change the complexion of the collaboration. The diverse and competitive U.S. production base, its typically much larger scale of activities, and its more flexible workforce policies offer more options for dealing with program adversities than purely European programs. Moreover, a willingness on the part of the U.S. government to retain indigenous U.S. production facilities in collaborative ventures with Europe can and has provided extra insurance against large program delays that have plagued some European collaborative ventures not featuring similar levels of production duplication. All the aforementioned factors have contributed to the generally favorable cost, schedule, and performance outcome of the multinational F-16 program.

The United States can realize economic benefits, as well as other less quantifiable but militarily important benefits, from appropriately structured coproduction programs. From an American perspective, coproduction of a U.S. system will rarely be economically more favorable than a direct sale to Europe. However, because our European allies are becoming less willing to accept the latter form of weapon transfer, the relevant basis for comparison is between the economics of a domestic program with no foreign sale and one that features foreign coproduction. There is no meaningful general formula to determine the cost consequences of coproduction arrangements, but one can estimate additional costs and savings for particular programs. In the F-16 program, the extra business generated as a consequence of European participation has offset most of the cost penalties from subcontracting in Europe. The estimated incremental cost to the Air Force program of 4-5 percent is small compared with typical major weapon system acquisition cost growth from other sources. Accountings external to the program per se estimate net economic benefits derived from R&D recoupment charges, reductions in plant overheads, reductions in unit costs from extra production, and a host of other factors. Less quantifiable but militarily important advantages are ascribed to the adoption of a common aircraft system by several NATO countries. Hence, from a U.S. perspective, a coproduction strategy does not necessarily involve a financial penalty.

Estimating the economic effect of the less frequent case of producing a European design in the United States is quite speculative, but such a strategy can involve sizable technical and programmatic risks. To estimate economic effects, some hypothetical development cost avoidance must be measured against the cost of nontrivial technology transfer efforts. These can include complicated and protracted license negotiations and technical data transfers and consequential changes to adapt a system to meet worldwide U.S. commitments and to make the system producible using the more capital-intensive U.S. manufacturing approach. Considerable testing may also be required to demonstrate the success of the technology transfer to the U.S. acquisition community. Almost every transfer of this type thus far has found U.S. program participants either not anticipating or underestimating the extent of the technology transfer task (e.g., four-fifths of Roland cost growth is attributed to estimating errors). This approach may carry its own set of risks, although perhaps of a different character than those associated with an alternative strategy of indigenous development.

From a European perspective, a policy of coproduction in lieu of direct purchases from the United States can entail considerable program cost penalties, but it can also provide some offsetting domestic benefits. Cost penalties can arise from a variety of factors, including the loss of economies of scale on the U.S. production line, the cost of the technology transfer, the duplication of production operations in Europe, and the participation of some less competitive European contractors. The last factor in particular makes it difficult to structure efficient coproduction programs. Contractors in the smaller European states participating in the F-16 program were estimated to be cost-competitive on less than a third of the airframe and avionics items analyzed under the most favorable of assumptions. Most of these items were fairly inexpensive. More generally, the prices of European goods adjusted for the combined effect of industrial price increases and fluctuating exchange rates have risen substantially faster than U.S. prices, similarly adjusted, during the past decade.

We estimated the original F-16 coproduction option to be about 34 percent more costly to the European participating governments than a hypothetical direct purchase. Only European governments can adequately weigh the cost penalty against such offsetting advantages as the opportunity to produce aircraft to satisfy their domestic needs as well as U.S. and third-country markets, stability in aerospace employment, technology transfer, industry modernization, and standardization of military equipment. A more cost-competitive aerospace production base may diminish some of the coproduction cost penalties for the larger European nations, but they may still be faced with the prospect of balancing potential program cost penalties against some of the benefits.

U.S.-European collaborative programs will not necessarily be characterized by excessive length and schedule slippage, although scheduling tasks will probably be more complicated. Critics frequently assert that collaborative programs in general tend to be longer and encounter more slippage than comparable national programs. After examining many European programs we found it difficult to distinguish between schedule tendencies brought about by European acquisition practices in general and those brought about by the participation of additional countries in a program.

There are striking differences in the typical lengths of U.S. and European military aircraft programs, whether the European program is national or multinational, particularly in the time between first flight and initial operational delivery. U.S. contractors typically use large labor inputs to begin production rapidly; European contractors operate under more restrictive workforce policies. As this transition from development to production is usually when nations join forces to collaborate in production, U.S. and European collaborators have to develop schedule arrangements that accommodate these considerable differences.

Scheduling complications that arise in coproduction programs involving the United States and Europe (e.g., F-104G, F-16) have not inevitably translated into longer programs or major schedule changes or slippage, although internal program schedule adjustments to accommodate different U.S.-European scheduling requirements have at times led to development and production concurrency that adds to program risks. Some programs featuring high degrees of production integration between countries have enjoyed considerable stability in production partly as a result of multinational pressures, an outcome many would view as more desirable than the fluctuating production rates characterizing typical U.S. domestic programs.

Recent policies calling for more limited and flexible offset goals and compensating coproduction arrangements appear to be well founded. Industrial offsets have been

one of the most contentious and frequently discussed issues in the F-16 program, with respect to the overall level of F-16 program production contracts placed in Europe and those placed within individual countries of the consortium. Although not strictly bound by the Memorandum of Understanding to place proportionate levels of production contracts in individual consortium countries, program management has, with great difficulty, tried to do so. Program management is generally bound to meet offset goals for the consortium within the program, with an as yet unexercised external offset escape clause to fall back on if that is not ultimately possible. Such arrangements are particularly burdensome when one is collaborating with small European countries that do not have fully developed aerospace industries. Using inexperienced producers to satisfy offset goals internal to a program can lead to increased subcontracting costs and programmatic risks. Recent DoD offset policies recognize these issues.

Certain features of multinational collaborative programs have made it more difficult to adhere to U.S. acquisition management procedures. Decisionmakers have departed from Defense Systems Acquisition Review Council sequential review and control procedures, policies that encourage the use of competition, and those that specify how mission element needs are identified and met. Broader considerations may justify less than strict adherence to policy guidelines, but decisionmakers should remain aware of the possible consequences of such deviation. Development or production decisions made without the benefit of information generated during development phases can increase technical risks. International program agreements that stipulate placement of work in specific geographic regions that feature little or no competition among potential suppliers can increase subcontracting costs. Early specification of hardware development responsibilities among nations without careful multinational coordination may stifle competition among technical responses to satisfy generic mission needs.

* * *

From a U.S. perspective in general and an Air Force perspective in particular, our examination of coproduction issues prompts some guidance regarding the avoidance of pitfalls, possible advantageous opportunities brought about by the F-16 program, and areas needing further review or research.

Current policies that encourage the maintenance of a largely indigenous U.S. production capability in coproduction programs should not be substantially altered. Experience with most European subcontractors in the F-16 program has been positive, but some key airframe, engine, and avionics deliveries have lagged. The reservoir of U.S. production support helped overcome the effects of long European lead times early in the program and has prevented production problems from slowing U.S. and European final assembly lines. More than a decade earlier, similar production assistance contributed to a generally satisfactory schedule outcome in the production of the F-104G in Europe. The flexibility to respond to adversity quickly and effectively distinguishes collaborative arrangements involving the United States from purely European ventures, a number of which have experienced considerable schedule slippage. Compensating actions can be taken to help offset some of the cost penalties from the duplication of fabrication and assembly responsibilities.

Government guidance to contractors with respect to program objectives, standardization goals, royalty payments, data rights, and third-country sales policies is

essential prior to the consummation of license agreements involving weapon transfers from Europe. Uneven or nonexistent government guidance in the early stages of the Roland program complicated the technology transfer and contributed to an underestimation of the effort involved for technology transfer, fabrication, and test. The government, including the Office of the Secretary of Defense and the Air Force, should guard against a repetition in future collaborative programs.

As F-16 subcontractors in Europe demonstrate their production capabilities, it may be economically advantageous to consider the direct purchase of selected items for incorporation as government-furnished equipment to reduce the cost burden of administrative loading charges applied by U.S. contractors. Loadings typically add 35 to 40 percent to the cost of items produced by European subcontractors for U.S. contractors in the F-16 program. The direct purchase option, which removes the loading, carries with it both benefits and disadvantages. It can lower the cost to the government and enhance a European contractor's apparent cost competitiveness, but it can also increase the management burden on the Air Force.

Although not bound by the F-16 MOU to do this, the United States may profit from the selective participation of European subcontractors in F-16 follow-on production. Continuing with the present coproduction arrangement for a follow-on buy of 738 aircraft for the U.S. Air Force would clearly cost more than a purely domestic purchase, but production quantity differences in the initial coproduction arrangement may give European subcontractors a cost advantage over U.S. producers for a small number of moderately priced part sets. A flexible contractor selection approach may yield modest dividends.

The Air Force should review the legal, regulatory, and policy solutions developed in recent collaborative programs to determine how the programs dealt with U.S. and European differences with respect to arms export policies, technology transfer restrictions, and weapon system acquisition practices. Although F-16 and Roland program participants have developed ad hoc solutions to many impediments to collaboration, frequently by the use of exceptions or waivers, they have had to live with the consequences of others. A systematic study is needed to determine which of these solutions, if any, should be institutionalized to facilitate future U.S.-European collaborative ventures.

The adequacy, from a U.S. perspective, of existing mechanisms (NATO and others) for tracking aircraft and other system replacement needs should be reassessed. Meeting early delivery dates specified by European governments contributed to the sale of the F-16 but also effectively foreclosed the sequential development and production of some key subsystems, introducing significant elements of risk into the program. The need to accommodate different national delivery requirements is inevitable, but planners of future U.S. weapon system developments could profit from earlier consideration of the replacement needs of potential customers.

More study is needed of the implications of collaboration on the subsequent operational support of weapon systems in general and, more specifically, on support of U.S. Air Force F-16s based in Europe. This study has examined the planning and execution of collaborative programs through the production phase without delving into operational support issues. One might profitably consider how multinational considerations introduced during development and production can influence the ultimate supportability of systems. Moreover, given the enormous costs involved in supporting modern weapon systems, further

study seems appropriate to consider how support policies can take advantage of certain features of coproduction. Unconventional support arrangements made possible by the F-16's atypical production arrangement might pay off in enhanced aircraft availability or lower support costs.

Coproduction, like any weapon system acquisition strategy, has drawbacks, but the record fails to show that it is as disadvantageous as many critics have asserted, particularly those who use the outcomes of a few purely European collaborative ventures to infer outcomes of prospective U.S.-European efforts. Its use in a variety of forms will probably grow because the governments involved want it.

The Air Force should attempt to play an active role during the planning stages of these coproduction programs. Armed with experience from the F-16 and other programs, it should press for arrangements that minimize some of the risks highlighted in this report and maximize the economic and other benefits coproduction can sometimes achieve. Only by playing an active role can the Air Force preserve the decisionmaking authority it generally enjoys in domestic programs, and it can do so with the knowledge that in the F-16 program, the most complicated example of U.S.-European collaboration yet attempted, it has thus far overcome most of the programmatic complications and achieved a generally favorable outcome.

ACKNOWLEDGMENTS

In the course of this research we visited numerous aerospace contractors in Europe and the United States. We gratefully acknowledge the data and insights provided by corporate officers and program management personnel from these contractors.

Aeritalia—Rome and Turin, Italy
Aerospatiale—Paris, France
Boeing—Seattle, Washington and Paris, France
British Aerospace—Kingston, Manchester, Warton, and Weybridge, U.K.
CFM-International—Paris, France
Euromissile—Paris, France
Fabrique Nationale—Herstal, Belgium
General Dynamics—Fort Worth, Texas; St. Louis, Missouri
Hughes Aircraft—El Segundo and Canoga Park, California and Paris, France
Lockheed—Burbank, California and Paris, France
Northrop—Hawthorne, California
Oldelft—Delft, The Netherlands
Philips—Eindhoven, The Netherlands
Pratt & Whitney Aircraft—West Palm Beach, Florida and Brussels, Belgium
Rolls-Royce—London, Bristol, Midlands, and Derby, U.K.
SABCA—Brussels, Belgium
SNECMA—Paris, France
Westinghouse—Baltimore, Maryland and Brussels, Belgium

Through the Society of British Aerospace Companies (SBAC) and the NATO Industrial Advisory Group, we conferred with representatives of over two dozen firms, including Marconi Avionics, Plessey Aerospace, Ferranti, EMI Electronics, Martin-Baker, Short Brothers (of Northern Ireland), and Messerschmitt-Bolkow-Blohm.

Also helpful was information supplied by European government agencies including the Ministries of Defense in The Netherlands and the United Kingdom; the Belgian General Staff; The Netherlands Ministry of Economic Affairs; and the Swedish Defense Materiel Administration. In the United States, we were aided by the F-16 System Program Office; the F-16 Program Element Monitor; and the Roland Program Management Office, among others.

Special appreciation is due P. G. Willekens of SABCA; C. G. Lundgren of the Swedish Defense Materiel Administration; N. W. Boorer and R. A. Harvey of British Aerospace; Sir Charles Pringle of SBAC; and Colonel K. S. Coryell, Colonel Jose Baca, and Lieutenant Colonel Vincent Calbi of the U.S. Air Force.

We were aided by numerous present and past colleagues at Rand, including Arthur Alexander, Allen Barbour, Teresa Barrett, Frederick Biery, Robert Dean, Peter deLeon, Edmund Dews, John Haaga, Joseph Large, Mark Lorell, Robert Perry, and Giles Smith.

Any remaining errors are the responsibility of the authors.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

ACF	Air Combat Fighter
AFB	Air Force Base
AFSC	Air Force Systems Command
AIS	Avionics Intermediate Shop
APC	Armored Personnel Carrier
ASARC	Army Systems Acquisition Review Council
AWACS	Airborne Warning and Control System
DoD	Department of Defense
DSARC	Defense Systems Acquisition Review Council
EPG	European Participating Governments
FOW	Family of Weapons
FRG	Federal Republic of Germany
FSD	Full Scale Development
GDP	Gross Domestic Product
GFAE	Government Furnished Aerospace Equipment
GFE	Government Furnished Equipment
IDL	Indentured Drawing List
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
LOA	Letter of Offer and Acceptance
LWF	Lightweight Fighter
MENS	Mission Element Need Statement
MOU	Memorandum of Understanding
MRCA	Multi-Role Combat Aircraft
NAMMA	NATO MRCA Management Agency
NTE	Not-To-Exceed
OECD	Organization for Economic Cooperation and Development
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
OUSDR&E	Office of the Under Secretary of Defense for Research and Evaluation
RDT&E	Research, Development, Test, and Evaluation
RFP	Request for Proposals
SAR	Selected Acquisition Report
SPO	System Program Office
TAC	Tactical Air Command
TTF&T	Technology Transfer, Fabrication, and Test
V/STOL	Vertical/Short Take-Off and Landing

I. INTRODUCTION

In recent years, several factors have combined to increase the consideration and actual incidence of collaborative weapons programs involving the United States and one or more foreign countries:

- The increasing development and production cost of modern weapon systems.
- Renewed interest in standardizing the weapons used by NATO nations.
- More intense interest—on both sides of the Atlantic—in improving European defense industrial capabilities and achieving a better balance of defense hardware trade between the United States and Europe.
- The growing number of European firms and industries with design and manufacturing capabilities on a par with their American counterparts.

One result has been the establishment of bilateral memoranda of understanding, primarily with NATO nations, promoting more reciprocal defense purchases. Another has been a variety of plans for increasing the number of multinational weapons programs. These plans call for extensive European involvement in the production of equipment for U.S. forces, a rare occurrence in the past when U.S. military services frequently acted as managers in the transfer of U.S. weapons to Europe.

The process of developing and producing hardware for the U.S. military services has always been complex. Compounding the technical difficulties posed by having to integrate high-technology components into an effective weapon system—for use in an uncertain combat environment and against a constantly changing threat—are the organizational difficulties created by the participation and scrutiny of a large number of government bodies in both the executive and legislative branches. When that process involves two or more nations differing in development and production approach and industrial capability, the process can be even more complex.

Although pressure for more collaborative programs has increased, the implications of such programs for cost and schedule outcomes and program management are not well understood. Further, most discussions to date have not had the benefit of a quantitative examination of past experience. In some cases, the decision to undertake a multinational venture has been made outside the service's customary weapons acquisition decisionmaking apparatus. affording the military services little time to assess the venture's merits and consequences or even plan an active role in structuring program ground rules.

This study is intended to improve our understanding of both the implications of multinational collaborative arrangements and the various ways to maximize their advantages while avoiding their pitfalls. It focuses on the most common form of multinational collaboration, coproduction.

COPRODUCTION: DEFINITION AND EXPERIENCE

There is no widely accepted definition of coproduction and many variations among programs with that label. As used in this study, coproduction includes any *international collaboration during the production phase of a major weapon system acquisition program*. That

definition covers many different types of collaborative arrangements, but most fall in three major classes:

1. Fully integrated coproduction, in which each participating nation purchases the same system and produces parts of each other's units (e.g., joint U.S. and European production of the F-16 for use in both U.S. and European air forces);
2. Foreign production, under license, of a U.S. design (e.g., Japanese, Canadian, and European production of the F-104, originally designed and produced for the U.S. Air Force); and
3. U.S. production, under license, of a foreign design (e.g., U.S. production of the French/German Roland air defense missile system).

The United States has had extensive experience with major weapon system coproduction over the last 30 years, although most of it involves foreign production of American designs. At least 44 different U.S.-designed systems have been produced in more than 20 different countries under more than 120 agreements. (See Appendix A for a list of programs.) They include such equipment as artillery, torpedos, and tanks; but the majority, including the largest and most publicized programs, involved aerospace systems produced in Europe, Canada, and Japan (see Tables 1 and 2). Licensed production of U.S.-designed subsystems is even more common. Many U.S.-designed aircraft engines have been produced under license in foreign countries for use on U.S.-designed aircraft (F-4, F-104, F-16, P-2, CH-53, etc.), as well as on foreign-designed aircraft (Canadian Buffalo, Italian G.91Y, Swedish Saab 105, Israeli Kfir, etc.). In addition, foreign-designed engines, including the Pegasus, have been produced under license in the United States for use on U.S. aircraft.

Three early programs demonstrated the feasibility of collaborative production in various settings and also foreshadowed many of the difficulties encountered in recent coproduction endeavors. U.S. production of the British Canberra bomber, renamed the B-57, illuminated

Table 1

MAJOR U.S. SYSTEMS PRODUCED BY FOREIGN NATIONS UNDER LICENSE (1947-1980)

Type of System	Number
Helicopters	16
Missiles	11
Fighters	6
ASW aircraft	3
Aircraft trainers	2
Armored personnel carriers	2
Howitzers	2
Projectiles	1
Other fixed-wing aircraft	1
Tanks	1
Torpedos	1

Table 2

NATIONS PRODUCING U.S. SYSTEMS UNDER LICENSE (1947-1980)

Belgium	9	
Denmark	5	
France	4	
FRG	8	
Greece	2	
Italy	20	
Luxembourg	1	
Netherlands	7	
Norway	8	
Portugal	2	
Spain	1	
Sweden	2	
Switzerland	1	
Turkey	3	
United Kingdom	11	
Total Europe:		84
Japan	22	
Republic of Korea	2	
Republic of China	2	
Total Far East:		26
Argentina	2	
Canada	12	
Australia	2	
Total Other		16
TOTAL		126

important differences in U.S. and European production methods that still exist today.[1] The Hawk surface-to-air missile program was the first instance of successful production of a U.S. design by a consortium of European nations, but participants had to overcome problems in the technology transfer process that also plagued a similar program two decades later.[2] The several F-104 programs demonstrated how coproduction could be used to develop extensive new aerospace manufacturing capabilities.[3]

Among more recent coproduction programs, the F-16 and the Roland have attracted the most attention. The F-16, a fighter developed by General Dynamics for the U.S. Air Force, is produced in the United States and four European nations. Each nation produces parts for every other nation under one of the most complex collaborative arrangements ever attempted. The Roland, an air defense missile system originally developed jointly by France

[1]For more information on the B-57 program, see Foxcurran (1979), p. 5.

[2]The main studies of the Hawk coproduction are Hochmuth (1963); Wenisch (1967); McGarrah (1965); Cornell (1969); and Foxcurran (1979).

[3]Histories of the F-104G program can be found in Cornell (1969), pp. 498-601; and Hochmuth (1963), Vol. II, Ch. 7, pp. 45-58. The political background of the program is discussed in Vandevanter (1964). The F-104J program is discussed in detail in Hall and Johnson (1967).

and the Federal Republic of Germany, is produced in the United States for the U.S. Army. Both of these programs provide numerous insights about the consequences and conduct of joint U.S.-European weapons production programs.

ISSUES POSED BY COPRODUCTION EXPERIENCE

An extensive and diverse body of literature is based on U.S. and European experience with coproduction. (The Bibliography covers the development of attitudes toward collaboration as well as discussions of the desirable roles of various industry, government, and supranational participants.) An illuminating portion of that literature addresses the perceived advantages and disadvantages of collaboration. This earlier work has for the most part relied on anecdotal, nonquantitative information, derived mainly from interviews with assorted program participants and very often based on examinations of all-European collaborative programs. A brief review of those perceptions is a useful backdrop for the material in the chapters that follow.

On the political level, coproduction has often been credited with strengthening ties within NATO. Thomas Callaghan has argued, with some support from history, that what the United States gets from coproduction is allies.[4] Various others have advocated broader transatlantic cooperation as a direct means of assuaging European doubts about American willingness to enter into a partnership and thereby forestall American-European weapons competition.[5] Some assert a high political content of these programs makes them less susceptible to major changes. This is variously viewed as an advantage or a disadvantage.[6]

Advocates of coproduction point to three military advantages. First, they argue that coproduction enhances NATO standardization through a harmonization of equipment, thereby alleviating what could become an "operational and logistics nightmare."[7] Second, they assert that coproduction increases the security of the United States and its allies by "encouraging multinational acceptance of strategic and tactical concepts and doctrine through the utilization of common military material."[8] Finally, they contend that coproduction results in a better product because it draws on the combined skills of several nations.[9] Recent work emphasizes standardization and interoperability more strongly.[10] That link has emerged in recent DoD statements, such as this one by former Deputy Undersecretary Dale Church: "We seek to enhance NATO military strength through rationalization, standardization, and interoperability of Allied military equipment."[11]

An opposing view holds that coproduction is usually chosen for national interests rather than to increase standardization, and whatever degree of standardization that may result

[4]Callaghan (1975b).

[5]Bajusz (1977), p. 4; Gessert et al. (1977), pp. 41-42.

[6]Foxcurran (1979), Ch. 12, p. 131; Hartley (1978), p. 5; U.S. House Committee on Armed Services, *NATO Standardization, Interoperability, and Readiness* (1978), pp. 123-126.

[7]Vitetta (1972), p. 12; and Cornell (1969), p. 627.

[8]U.S. House of Representatives, *Foreign Assistance and Related Agencies Appropriations for 1976* (1976), p. 220; Catledge and Knudsen (1969), p. 183; Vandevanter (1964), p. 2; and Cornell (1969), p. 196.

[9]U.S. GAO "A New Approach is Needed . . ." (1979), p. 48; Vandevanter (1964), p. 2.

[10]Gessert et al. (1977), p. 1; and Bajusz (1977), pp. 1, 6-7.

[11]Dale W. Church, Deputy Under Secretary of Defense (Acquisition Policy), *Information on Defense Procurement from the Western European Union (WEU)*, a letter, U.S. Department of Defense, Washington, D.C., 21 August 1978, p. 7.

quickly disappears as each nation introduces its own product improvement program.[12] Four disadvantages of coproduction with military implications have been suggested:

- In some cases standardization might make it easier for the Soviets to counter NATO capabilities than would a variety of different systems.[13]
- Systems will often fall short of operational requirements. It is sometimes difficult to reach agreement on requirements within one country; and some fear that collaboration, requiring the agreement of more than one country, will produce systems so distorted by negotiation and compromise that they represent no one's first choice.[14]
- Systems will generally take longer to field as a result of the multiple partnerships, involving more development aircraft, more subcontractors, more production lines, and more schedule slippage, as well as conflicts over system specifications delaying the start of the program.[15]
- Collaboration will make the United States dependent on foreign sources for materials and support, or on foreign production lines and workforces, thus weakening U.S. response capability. The Army's concern over this is illustrated by their willingness to use the European-developed Roland only if it is produced in the United States because "it would be militarily unacceptable for the Army to be forced to rely on a foreign producer; in the event of war it might be deprived of crucial deliveries."[16]

Coproduction's proponents contend that it will decrease the unit costs of systems and eliminate duplicative R&D, logistics, and support systems.[17] In addition, advocates anticipate that economies of scale resulting from longer production runs will bring employment stability and higher returns on investments,[18] and will improve the technological base of related industries.[19]

Others have predicted that coproduction will increase costs at almost every stage of procurement, beginning with higher program initiation costs.[20] Among the reasons cited for such increases are the general administrative demands of an international program,[21] the small scale of production in European industries,[22] the need for additional test and evaluation aircraft by the various partners,[23] management of numerous subcontractors and final assembly lines in several countries,[24] and currency fluctuations.[25] The issue of subcontractors is of special concern. The political underpinnings of coproduction encourage economically inefficient selection criteria for subcontractors,[26] which, in turn, are aggravated by the difficulty of evaluating the cost of proposals submitted by foreign contractors.[27] These factors

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[12]Konings (1979), pp. 21-26.
[13]Ibid., pp. 35-36.
[14]Vitetta (1972), pp. 12, 22; Vandevanter (1964), p. 93; and Cornell (1969), p. 708.
[15]Hartley (1978), p. 17; Vitetta (1972), p. 12; and Vandevanter (1964), p. 49.
[16]Bajusz (1977), p. 46; and Cornell (1969), pp. 665-669.
[17]Gessert et al. (1977), p. 45; U.S. House of Representatives, *NATO Standardization, Interoperability, and Readiness* (1978), p. 1226.
[18]Gessert et al. (1977), p. 45.
[19]Bajusz (1977), p. 37; Catledge and Knudsen (1969), p. 16.
[20]Lockheed-California Company, *World Wide F-104 Program Press Book*, Burbank, California, undated, p. II-1; and Hartley (1978), p. 13.
[21]Hartley (1978), p. 11.
[22]Konings (1979), p. 19.
[23]Hartley (1978), p. 17.
[24]Vandevanter (1964), pp. 51-52.
[25]U.S. GAO, *The Multinational F-16 Aircraft Program: Its Progress and Concerns* (1979), pp. 8-11.
[26]Hartley (1978), p. 16; Gilster (1978), p. 5.
[27]Gessert et al. (1977), p. 73.

have been seen to combine to cause cost overruns, managerial inefficiencies, and production delays, distorted further by currency fluctuations.[28]

PURPOSE AND APPROACH OF THIS STUDY

The central purpose of this study was to determine the effect of multinational coproduction arrangements on two critical measures of weapons acquisition program success: program cost and program schedule. In the course of the study we addressed many of the questions raised above, including

- Does coproduction impose a consistent cost penalty on the United States?
- Do collaborative programs take longer and experience more schedule slippage than comparable national programs?
- Are European collaborative programs a good guide for predicting the outcomes of joint U.S.-European programs?

The study's main objective was to assist persons involved in planning and managing future U.S.-European coproduction efforts by providing quantitative insights into factors likely to affect program success.

To build a broad and detailed data base, we studied a large number of military aerospace development and production programs.[29] The study concentrated on American and European experiences but included examinations of other programs as well. In addition to evaluating program outcomes, we attempted to identify and, where possible, quantify critical trends and differences in U.S. and European practices that are likely to influence the conduct and course of future joint programs. In this vein, we undertook an extensive examination of the F-16 program, the largest international coproduction program to date.

Although the dominant perspective selected was that of the United States Air Force, we addressed additional dimensions in several areas. We necessarily excluded several important related issues, including codevelopment and weapons standardization, from central emphasis, although the latter subject is discussed as it relates to coproduction and in making general comparisons of collaborative and noncollaborative programs. For several reasons, we have tried to gain additional insights from experiences accumulated in codevelopment programs, some of which illustrate features of the European acquisition environment that are independent of any particular collaborative arrangement. Most codevelopment programs also feature some form of coproduction; hence, they may also illustrate various implications of coproduction. Codevelopment and coproduction programs share some problems, and the techniques used to deal with some of those problems may be applicable to either kind of program. Many coproduction programs also involve some development while the collaborative arrangement is in force; hence, development-oriented issues illustrated by codevelopment programs may at times be relevant.

ORGANIZATION OF THE REPORT

The key to understanding the special consequences of international involvement in U.S. weapons production programs is appreciating the marked U.S. and European differences in

[28]Hartley (1978), p. 16; Konings (1979), pp. 13-14; and U.S. Senate Appropriations Committee, *Department of Defense Appropriations Fiscal Year 1979*, 95th Congress, 2nd Session, Part 6, p. 186.

[29]Although we directed most of our attention toward military systems, we also examined several collaborative commercial transport programs.

such things as production scale, workforce policies, schedule philosophy, and manufacturing methods. Those differences and others are described and, where possible, quantified in Sec. II. Section III discusses the implications of those differences for collaborative production programs. Section IV is a detailed analysis of the F-16 program, which is the largest and most important American coproduction effort to date. The report concludes with a summary of major findings and policy-related observations in Sec. V.

II. SETTING FOR COLLABORATION: U.S.-EUROPEAN DIFFERENCES

Fundamental to an understanding of the probable outcomes and pitfalls of U.S.-European weapons production collaboration is an appreciation of a wide range of U.S. and European differences. The most important contrasts concern the scale and breadth of defense economic activities and the policies for managing defense industry workforces and have contributed to significant differences in U.S. and European aerospace design methods, development practices, and manufacturing methods. When considered together, the differences in scale, workforce policies, and acquisition processes help explain the strikingly different outcomes of U.S. and European military aerospace programs.

Although in most cases U.S.-European differences overshadow inevitable differences between European nations, generalizations about Europe are not always appropriate. Consequently, data in this section are disaggregated when possible and appropriate. The following discussions should be viewed as a backdrop for the consideration of the implications of production collaboration in Sec. III.

SCALE

There are significant differences in the scale of industrial and defense activities of the United States and its European NATO Organization allies.[1] These scale differences help explain why European nations individually and collectively approach the acquisition of military equipment differently than does the United States. To collaborate successfully, the United States and its NATO allies must devise collaborative arrangements that accommodate the scale differences and the different acquisition approaches they engender.[2] Those differences also represent the primary reason why U.S.-European collaboration needs to be viewed differently than all-European ventures. As groundwork for the more extensive discussion that follows, here we discuss scale differences in the following areas:

- General economic and industrial activity.
- Defense expenditures and military aircraft inventories.
- Aerospace production at both the industry and project levels.

In gross economic and industrial terms, NATO Europe as a whole is roughly comparable to the United States. With a combine[illegible] ulation close to 50 percent greater, the 12 European NATO nations registered an aggregate GNP 1.4 r[illegible]ent less [illegible] that of the United

[1]Current European NATO allies are Belgium, Denmark, France, Germany (FRG), Greece, Italy, Luxembourg, The Netherlands, Norway, Portugal, Turkey, and the United Kingdom. France withdrew from the Alliance military organization in March 1966 but is included in both the defense and nondefense comparisons in this subsection. Iceland is a member of NATO and often listed as a European NATO member, but it is excluded here because it possesses no military forces or defense industries. The United States and Canada are the other members of NATO.

[2]Arrangements developed for all-European collaborative programs involving more modest scale differences will not always be adequate for programs involving the United States. For example, sizing production shares on the basis of the size of each country's planned buy may not be acceptable considering the vastly larger U.S. defense requirements.

States.[3] But neither the 12 European NATO nations nor even all the 18 nations of non-Communist Europe combined[4] can match the U.S. level of defense expenditures. In 1979, total U.S. defense expenditures exceeded the aggregate outlays of all 18 non-Communist European states by over 35 percent and that of the 12 European NATO members by over 50 percent. France, which spends more on defense than any other non-Communist European state, expended less than 15 percent of the U.S. total in 1980.

Not only do U.S. defense expenditures exceed those of individual NATO countries and NATO as a whole in absolute terms, they also exceed when measured per unit of overall economic activity, central government expenditures, or population. In 1978, for example, the United States devoted 5.2 percent of its GNP and 24 percent of its central government expenditures to defense spending. The comparable figures for NATO Europe were 3.4 percent and 12.2 percent. The relative defense spending patterns in the United States and NATO Europe in 1978 are not uncharacteristic of the preceding decade as a whole. Per capita, U.S. military expenditures in 1977 were about 2.5 times the level of NATO Europe and about 60 percent higher than the Federal Republic of Germany, which spent more per capita than any other European country in that year.[5]

NATO Europe is, of course, a patchwork of sovereign states, stretching from the Arctic Circle to the Middle East; it is unified neither politically nor economically and cannot be considered as a single bloc. The North Atlantic Treaty merely commits member governments to consult together in planning their common defense. In addition to substantial political, cultural, and linguistic differences, the NATO states vary considerably in levels of economic development and industrial and defense capabilities. For example, Portugal and Turkey are underdeveloped economically compared with Germany or France. If for no other reason than differing levels of industrial development, capabilities, and defense effort, an aggregated view of NATO Europe can be misleading, especially because past transatlantic and intra-European collaborative programs have rarely involved more than four NATO European states. When the United States is compared with a subset of NATO European countries, the scale differences in industrial and defense activities are far more pronounced.

To illustrate these points, NATO Europe may be divided into three tiers based on each member's overall industrial and defense activities.[6] The three most populous and highly industrialized NATO European states—Britain, France, and the FRG—constitute the first tier and hold a dominant position in NATO Europe. The middle tier of states includes Belgium, Italy, and The Netherlands. The smaller and less industrialized NATO powers of Denmark, Greece, Luxembourg, Norway, Portugal, and Turkey make up the third tier.

Most major intra-European collaborative programs have taken place between two of the three first-tier states. Nonetheless, even the combined industrial and defense efforts of these three nations are much smaller than that of the United States, particularly in total defense expenditures and defense industry output, and defense market (see Fig. 1). The second tier states support substantial industrial and defense capabilities; however, they do not attempt to maintain as complete a spectrum of defense industry capabilities as do the countries of the first tier. The third tier countries, which generally concentrate their defense industry efforts

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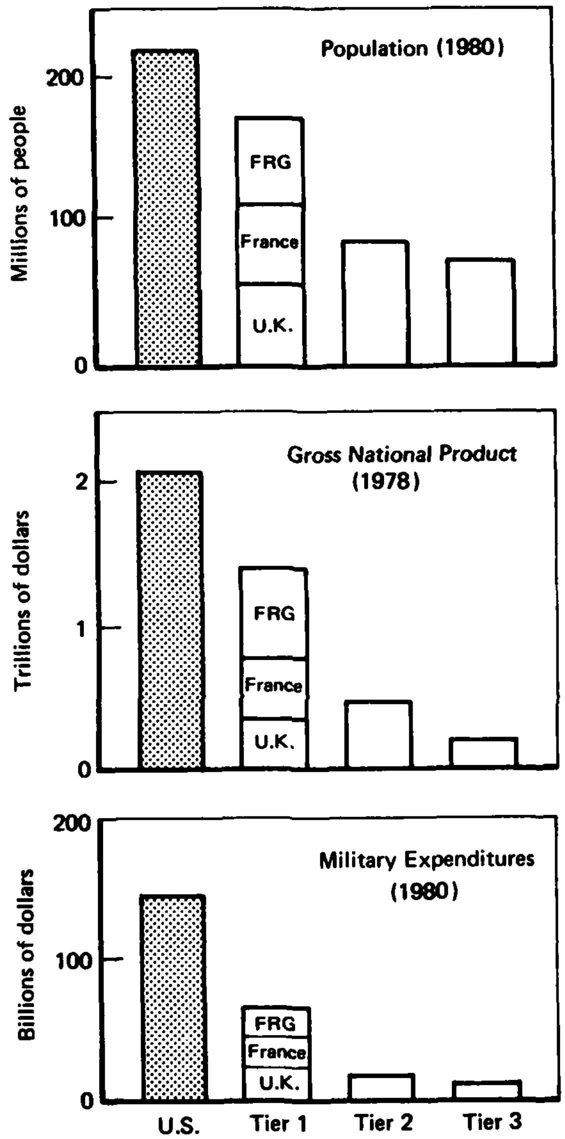
[3]Statistical Office of the European Economic Community, *Basic Statistics of the Community*, 15th ed., Brussels, 1980.

[4]Sweden and Switzerland, neutral countries outside the NATO framework, also support extensive defense industry capabilities and armed forces.

[5]See United States Arms Control and Disarmament Agency, *World Military Expenditures and Arms Transfers 1969-1978*, Washington, D.C., December 1980; International Institute for Strategic Studies, *The Military Balance, 1979-1980*, London, 1979.

[6]See Gessert et al. (1979), Vol. II, pp 22-23.



SOURCE: The International Institute for Strategic Studies, *The Military Balance, 1980–1981*, London, 1980.

Fig. 1—Selected economic indicators for the United States and NATO Europe*

* NATO Europe is divided into three tiers: Tier 1 consists of the Federal Republic of Germany, France, and the United Kingdom. Tier 2 consists of Belgium, Italy, and The Netherlands. Tier 3 consists of Denmark, Greece, Luxembourg, Norway, Portugal, and Turkey.

in narrow areas, are small in gross economic and defense industry terms even by European standards.

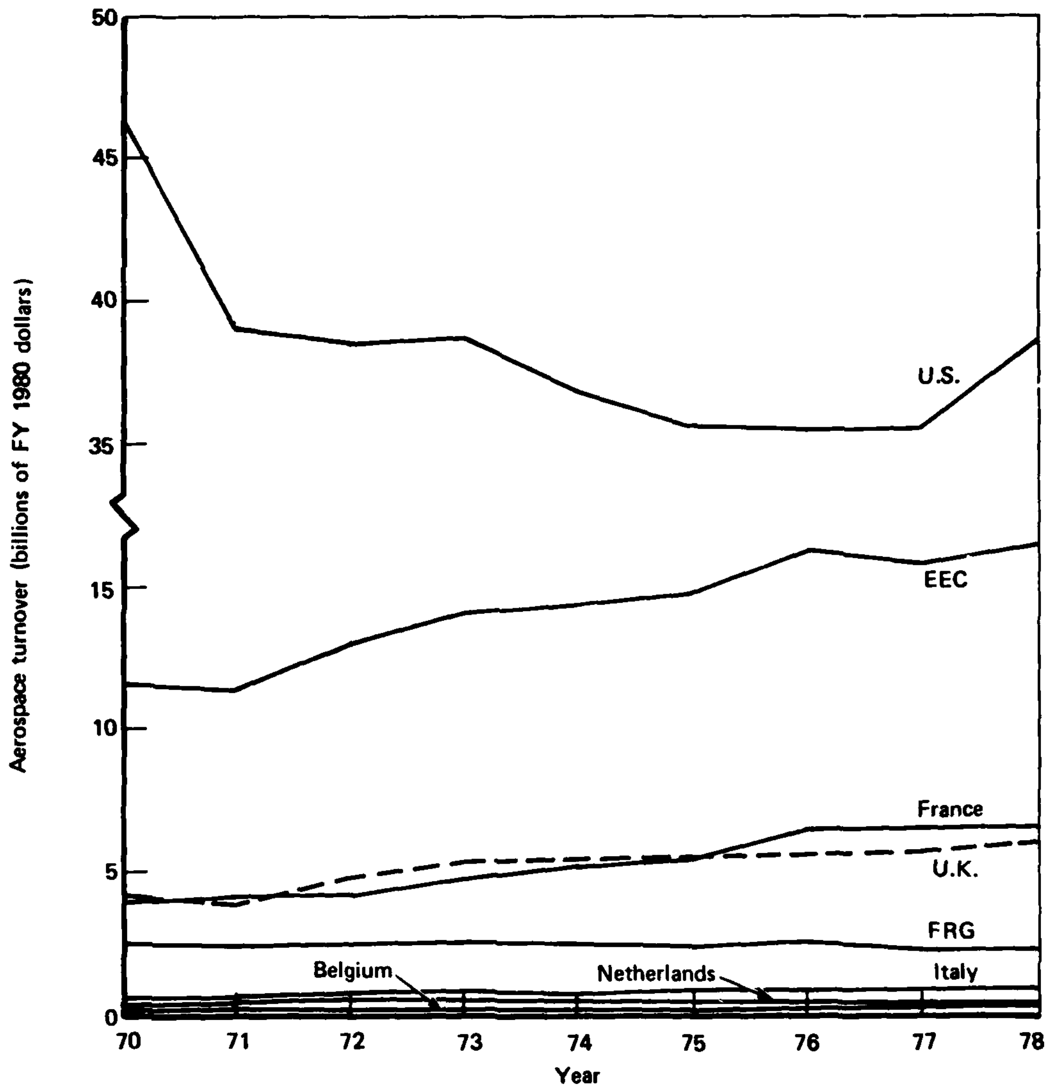
Although the differences between the United States and NATO Europe do not carry over to ground forces and equipment, the defense spending differential is reflected in military aircraft inventories. The U.S. Air Force operates about 29 percent more combat aircraft than all the NATO Europe air forces combined. The U.S. *Navy* flies almost twice as many combat aircraft as the largest European *air force,* and the U.S. Marines possess more aircraft than all but three NATO European air forces. The U.S. Army owns over 3½ times as many helicopters as all the armies of NATO Europe combined.[7]

The relative advantage the United States holds in numbers of weapon systems over NATO Europe and the large numbers of U.S. weapons in European inventories are a manifestation of the large differences not only in total military expenditures and defense market size but also in defense industry activity and capabilities. The total annual average armaments industry output of NATO Europe from 1967 to 1976 amounted to just over one-third that of the United States.[8] French industry, with the highest NATO average annual output during this period, produced defense products valued at about 12 percent of the U.S. figure, Britain averaged about 9 percent, and the FRG about 7.5 percent. Largely because of the war in Southeast Asia, estimated U.S. armaments industry output as a percentage of GNP consistently remained far above any of the NATO European states from 1967 through 1976. Not surprisingly, the average yearly value (in constant terms) of U.S. military exports during this period exceeded that of all the six European states by over 200 percent.[9] Thus, in many respects, U.S.defense industry production and the size of the defense market surpass that of all 12 European NATO nations combined.

The earlier categorization of NATO Europe's three tiers of nations generally holds up when one more specifically considers aerospace industry turnover (total income), with France and the United Kingdom sharing leadership, followed at some distance by the FRG (see Fig. 2). Belgium, Italy, and The Netherlands fall into the second tier. The third-tier NATO countries do not have significant aerospace industries. Outside the NATO sphere in Western Europe, Sweden has the most active aerospace industry, with sales falling roughly between those of Italy and the FRG. The trends in sales depicted in Fig. 2, which reflect differences in the volume of European aerospace activity, indicate that European aerospace industries are not a single homogeneous entity.

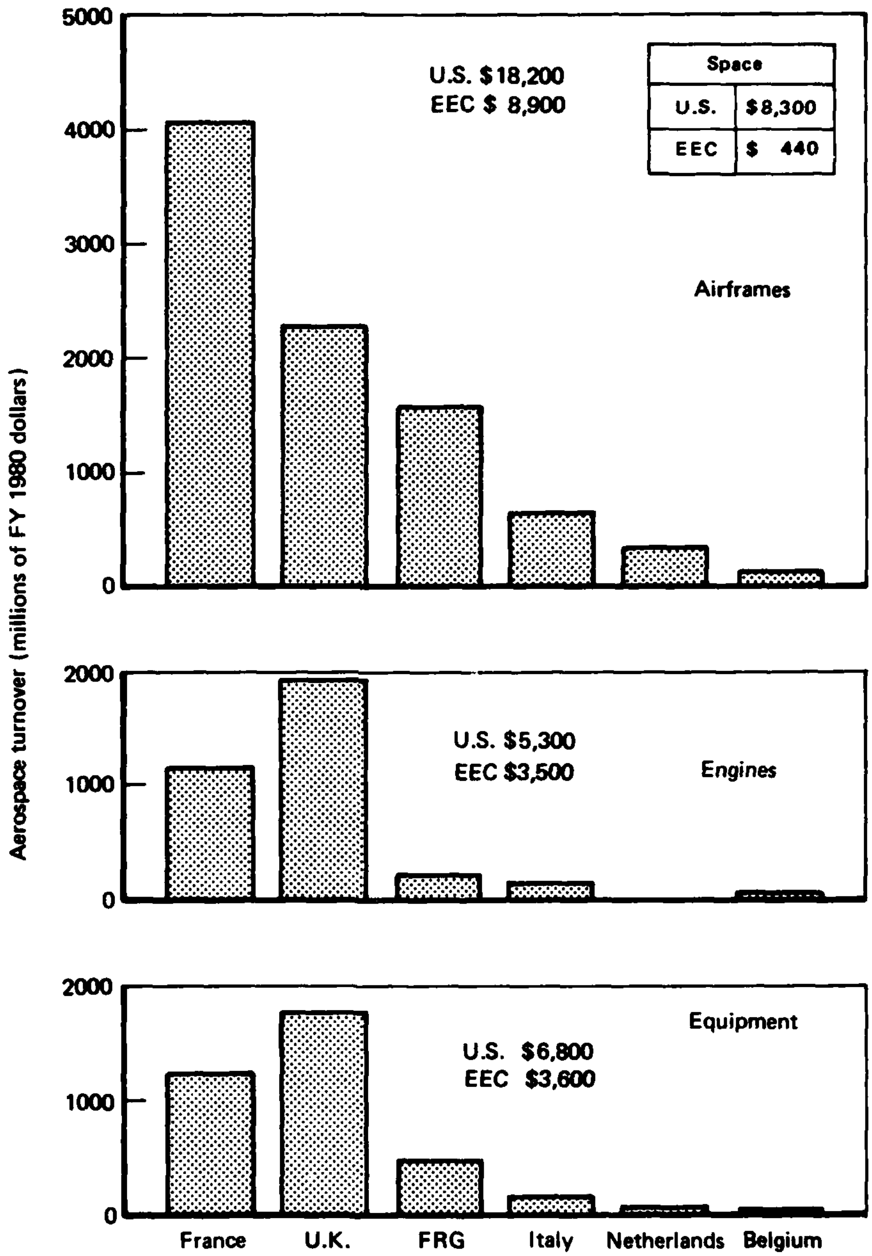
Comparing sales in broad product areas provides some clue as to the breadth of product lines and the extent of the aerospace equipment infrastructure in European industry. Figure 3 indicates that the United Kingdom shows the greatest balance across product areas (excluding space), whereas a smaller country, such as The Netherlands, emphasizes airframe production but does not have a major indigenous engine production capability. Conversely, Belgian industry is active in both airframe and engine production. This kind of selective product emphasis, particularly in the context of collaboration with countries in the third tier and in some cases with those in the second, can make it exceedingly difficult to distribute coproduction responsibilities equitably across a consortium. To the extent that the first tier countries have a sufficiently large and varied industry infrastructure in each of the product areas, this factor presents less of an obstacle when the United States collaborates with them.

[7]The International Institute for Strategic Studies, *The Military Balance, 1980-1981*, London, 1980.
[8]Britain, France, the FRG, Italy, The Netherlands, and Belgium account for over 92 percent of NATO Europe's arms industry output.
[9]Gessert et al. (1979), Vol. II.



SOURCE:
EEC staff working paper SEC (80) 1287;
U.S. Department of Defense Deflators (TOA) March 28, 1980.

Fig. 2—Comparison of U.S. and European aerospace industry turnover in 1978



SOURCE: EEC staff working paper SEC (80) 1287;
U.S. Department of Defense Deflators (TOA) March 28, 1980.

Fig. 3—Comparison of aerospace industry turnover by product area in 1978

Another measure of activity is production continuity. If we consider the production of major jet-powered military aircraft, which generally requires the most sophisticated industrial base, we see that French, Italian, and British industries enjoyed production continuity throughout the past decade (see Fig. 4). The FRG, The Netherlands, Belgium, and Spain, however, experienced gaps in production, which were filled through subcontracting work (e.g., aircraft parts fabrication, overhauls) or the production of other aircraft types,[10] both commercial and military. Without the continuing impetus of new programs, production capabilities and facilities can fall into decline, requiring more time and effort to renew production when collaboration does occur. Such was the case in The Netherlands and Belgium when their industries began preparing for F-16 production.

All the European nations depicted in Fig. 4 have demonstrated the ability to produce reasonably complex supersonic aircraft, although many of those systems have a considerable U.S. parts content. France, the United Kingdom, West Germany, Italy, and Sweden have designed supersonic aircraft either indigenously or collaboratively.[11] U.S. inventory requirements have yielded a greater diversity and number of new aircraft designs and more continuing production programs than any single European nation. A discussion in Sec. III will indicate that the present and projected size of domestic and foreign markets for U.S. combat aircraft and jet trainers exceeds Western Europe's aggregated total markets by a substantial margin.

One implication is that the United States aerospace industry will continue to enjoy more new programs, as well as the advantage of producing aircraft in greater numbers (and usually at higher production rates) than its European counterparts.[12] The greater scale of U.S. aerospace activity is usually accomplished through larger projects, whose larger and longer production runs offer more opportunities for realizing the beneficial effects of capital investment and workforce learning. As will be shown in Secs. III and IV, in a collaborative program, when the U.S. requirement is much larger than that of its partner(s), the scale difference serves as valuable insurance against major schedule difficulties.

Not only are U.S. programs much larger, U.S. aerospace firms tend to be larger than European firms. This disparity has prompted the consolidation of national European firms into larger, more competitive operating units. Many of these consolidated firms have been transferred from private to government ownership, at times for commercial stability and sometimes for political reasons. Figure 5 depicts the essential features of that aircraft industry consolidation in France, the FRG, and the United Kingdom. However, Table 3 shows that even with this consolidation, several U.S. aerospace firms are larger than even the largest European aerospace firms. The formation of such partnerships as Airbus Industrie, Panavia, and Euromissile, made up of these larger entities backed by government and private sector funding, has allowed European industry to compete on a more equal footing with U.S. industry. Even then, European industrial officials suggest that members of the first tier must be selective in their product emphasis, for they cannot compete with U.S. industry across the

[10]For example, SABCA of Belgium produces empennages for Mirage F1 aircraft, and MBB of the FRG had major responsibilities on the A300 commercial transport program. Both service F-104G aircraft.

[11]The difficulties encountered in European collaborative programs will be discussed below. For a recent analysis of several such programs, see Mark A. Lorell, *Multinational Development of Large Aircraft: The European Experience*, The Rand Corporation, R-2596-DR&E, July 1980.

[12]Simple comparisons of production runs provide one rough indication of differences in U.S. and European project sizes. Some examples: 1,545 C-130s have been produced since 1955; the similar Noratlas and Transall programs have involved 428 and 178 units respectively. Over 520 P-3s have been produced, but only 90 Atlantiques. Through 1981, 1,577 A-7s and 438 A-10s had been manufactured; the Jaguar program has numbered just 443 units. Examples from other aircraft programs abound. The United States also produces larger quantities of lower-cost items, such as air-to-air missiles.

board in all kinds of aerospace systems.[13] In addition, the size of U.S. firms often permits scale economies and advantageous commercial practices (such as volume purchases) that are not available to smaller European companies.

Notwithstanding these U.S. advantages, European industry has competed effectively in world markets in certain selected product areas such as head-up displays, ejection seats, and flight simulators. Moreover, some European nations that have historically relied on U.S. aircraft are electing to replace some of them with aircraft designed and produced indigenously or collaboratively (e.g., replacement of F-104Gs and F-4s by the two versions of the MRCA). Additional commercial programs such as Airbus have expanded the business base. The modernization of facilities resulting from these programs (e.g., production modernization at the MBB facility in Augsburg to support MRCA production) should improve European industry's ability to collaborate or compete in the future. Whether European industry can maintain the continuity of programs needed to sustain a competitive position remains to be seen.

WORKFORCE POLICIES

The most pervasive U.S.-European difference that can affect the character and success of collaborative programs involve workforces. The adage that "Americans fit the workforce to the program, while Europeans fit the program to the workforce" is largely true: Different schedule tendencies noted below result in part from different workforce policies, which are driven in part by the scale differences noted above.[14]

The goal of long-term workforce stability, especially at the firm level, is prominent in Europe. This is apparent from examinations of individual firm employment histories. Dassault's workforce stayed between 14,693 and 15,161 through most of the 1970s; the components of British Aerospace were nearly as stable. There are many examples of both dramatic fluctuations and stability in the United States. Boeing's employment shrank by about 60 percent between 1968 and 1971, and grew by that much during the remainder of the 1970s. Grumman's employment did not deviate very much from the 28,000 level at which it began and ended the decade. On average, annual employment fluctuations are usually higher in the United States; in some years, the difference can be quite pronounced (see Fig. 6).

European industries have significantly less flexibility to change labor inputs because of more restrictive layoff policies, more restrictions on the use of temporary workers, worker preferences for single-shift operations, and their antipathy toward overtime. The layoff restrictions stem from very stringent advance notice and severance pay requirements, often amounting to one month's pay per year of service, up to 20 (as in the case of Rolls-Royce). In general, Dutch firms cannot release workers without demonstrating financial losses. Many of these requirements have statutory roots and others derive from well-established understandings between management and labor unions.[15]

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[13]Allen Greenwood (1978a, p. 502) of British Aerospace has said, "We [European industry] must choose our ground carefully so as not inevitably to come into open conflict with the American competition."

[14]Our discussion does not present direct measures of relative costs of labor and capital, other very important determinants of workforce policies. In general, because of the typically smaller scale of production, for economic reasons Europeans choose a labor-intensive approach more frequently than Americans.

[15]General reference sources on these subjects include K. Daly and A. Neff, "Productivity and Unit Labor Costs in Eleven Industrial Countries, 1977," *Monthly Labor Review*, November 1978; U.S. National Commission for Manpower Policy, *Recent European Manpower Policy Initiatives*, Special Report No. 3, November 1975; D. Jenkins, "Job-Security Measures Growing Throughout Europe," *World of Work Report*, Vol. 3, July 1976.

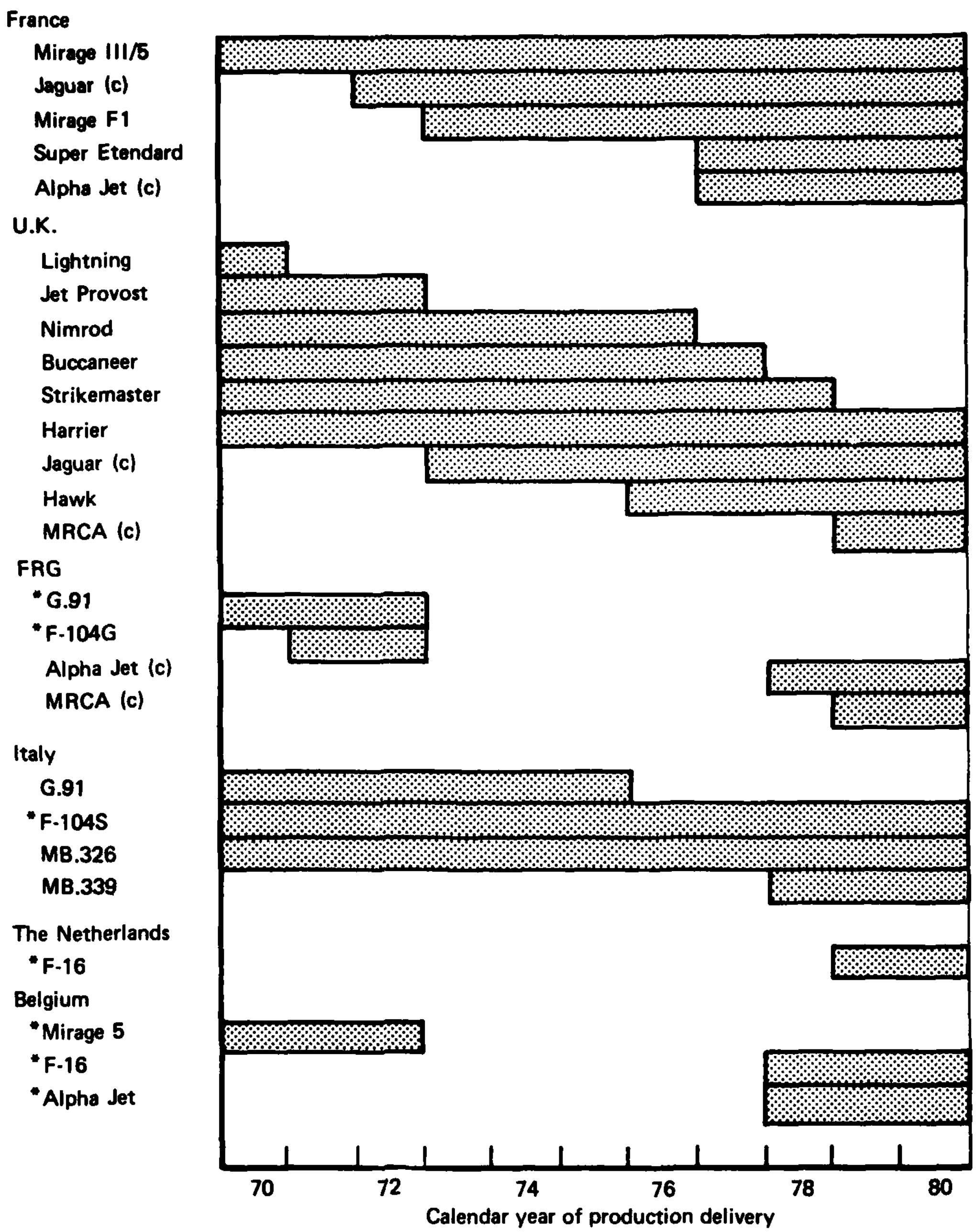
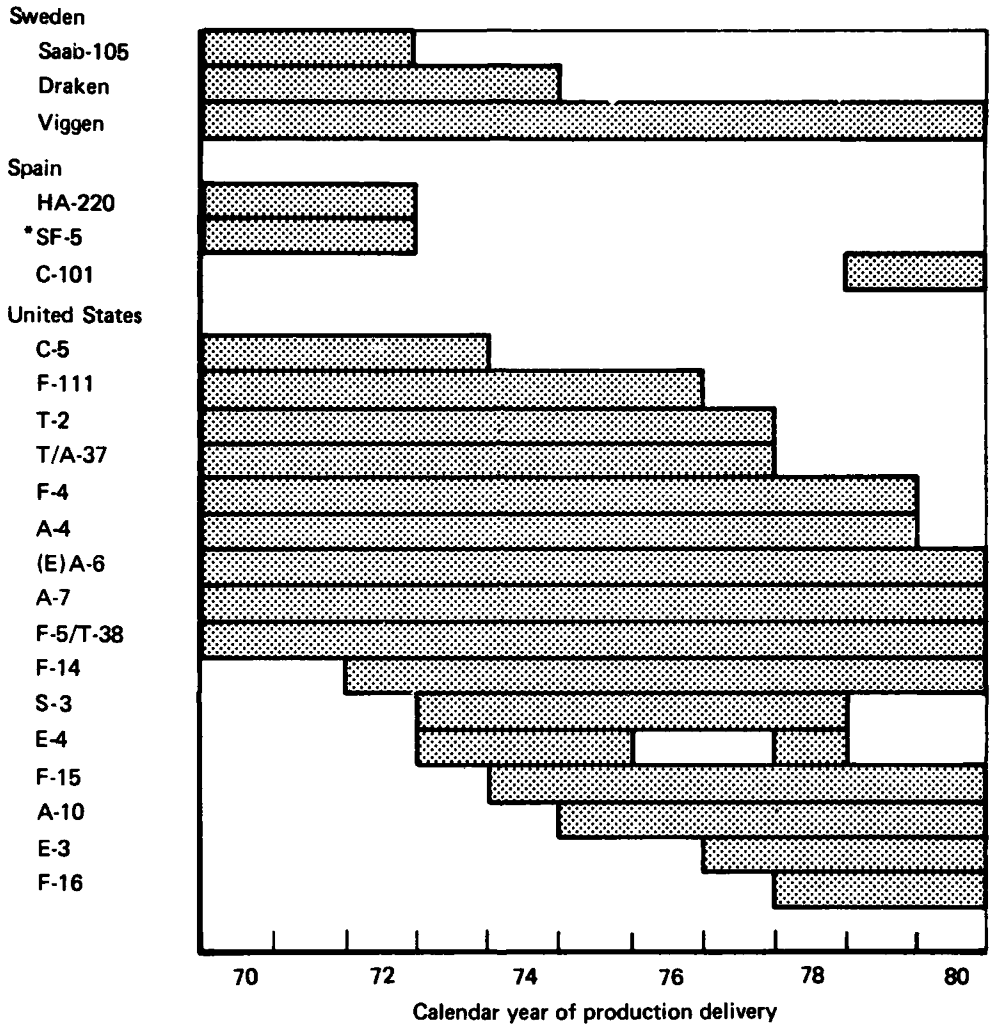


Fig. 4—Major turbojet/turbofan powered military aircraft program production activity†



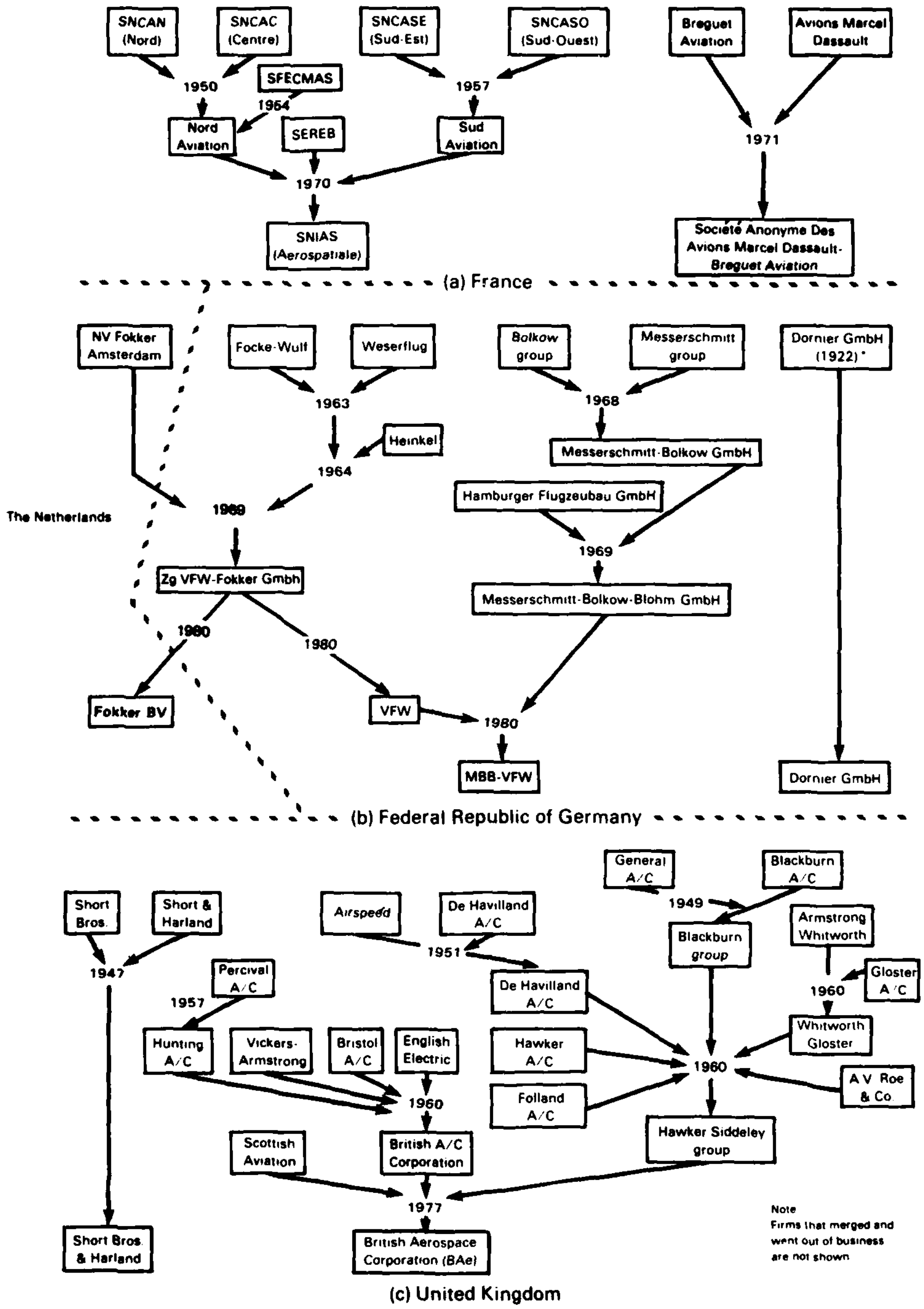
SOURCES: *Jane's All the World's Aircraft* (various issues); Air Force/DoD/Navy program documents; various periodicals; Smith and Friedmann (1980)

(C) Co-development

* Foreign design

† Accounting does not include some miscellaneous business jet and air transport production for the military for training, patrol applications, etc. (e.g., B-737, Falcon, DC-9). Accounting only reflects production vehicles deliveries.

Fig. 4—continued



SOURCES: Greenwood (1978a) pp. 497–498, and *Jane's All the World's Aircraft* (various years).

* Company formation

Fig. 5—Consolidations of French, German, and British aircraft industries

Table 3

EMPLOYMENT AND TURNOVER OF SOME MAJOR U.S. AND EUROPEAN AEROSPACE FIRMS

Firm	Approximate Employment (1979)	1979 Turnover (Millions of 1979 dollars)[a]
Europe		
British Aerospace	75,000	2,260
Rolls-Royce	56,600	1,680
SNIAS (Aerospatiale)	37,200	2,710
Dassault-Breguet	15,600	1,700
SNECMA	10,700[b]	540[b]
Turbomeca	4,500	220
MBB	26,500[c]	1,450
VFW	12,000[c]	560
Dornier	8,000	480
MTU (Munich)	6,200	280
United States		
Boeing	98,300	8,130
McDonnell Douglas	82,700	5,280
General Dynamics	81,600	4,060
Lockheed	66,500	4,060
United Technologies		
Power (Pratt & Whitney)	—	3,690
Flight Systems (Sikorsky)	—	850

SOURCES: *Principal Companies of the European Economic Community 1979/80*, Graham & Trotman Ltd., London, 1979; *Principal International Businesses, 1981*, Dunn & Bradstreet, New York, 1980; *Interavia*; *Flight International* (various issues); and annual reports of U.S. firms.

[a]Rounded to nearest $10 million.

[b]Figure for 1978.

[c]Figure for the end of 1980.

Some industries in Europe, such as those in which the manufacturing process is particularly capital intensive (e.g., turbine engines), do employ more than one shift to recover their investments. For example, Fabrique Nationale uses two shifts for the assembly and test operations in the F100 engine program. For the most part, however, multiple shifts are unusual, particularly in European airframe and avionics production.

Union opposition to rapidly expanding or contracting workforces is generally grounded in the belief that steady long-term production affords more job opportunities for more people than programs with very dynamic production rates. Such opposition is not always rigid and has been relaxed to accommodate new business opportunities. For instance, to provide its civil airline customers with timely aircraft deliveries, Aerospatiale employs multiple shifts in the Airbus program.[16]

[16]"Aerospatiale Delivers Final A310 Center Section," *Flight International*, 23 May 1981, p. 1531.

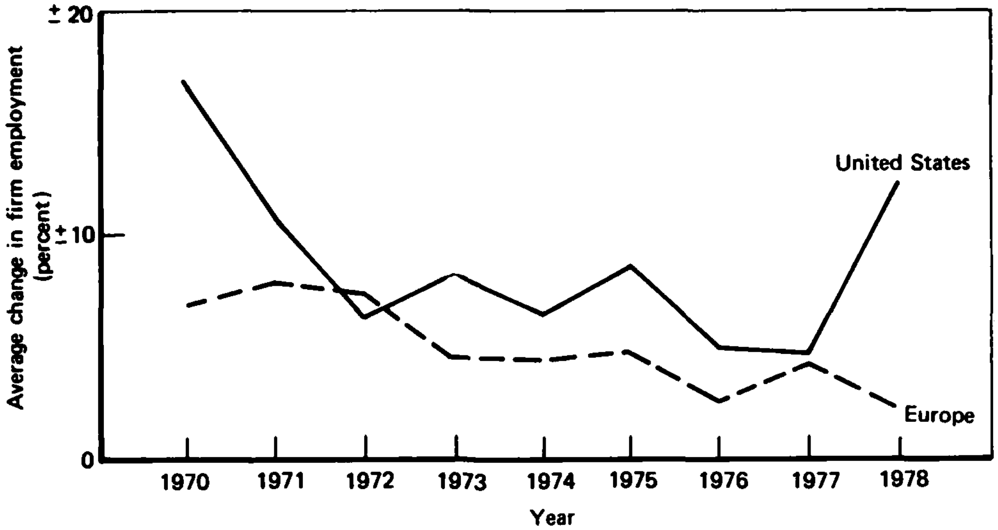


Fig. 6—Average annual employment fluctuations in United States and European aerospace firms*

*Sample size: United States, 8 firms (est. 1978 employment: 470,000); Europe, 22 firms (est. 1978 employment 475,000). Not all firms are included in each year's average.

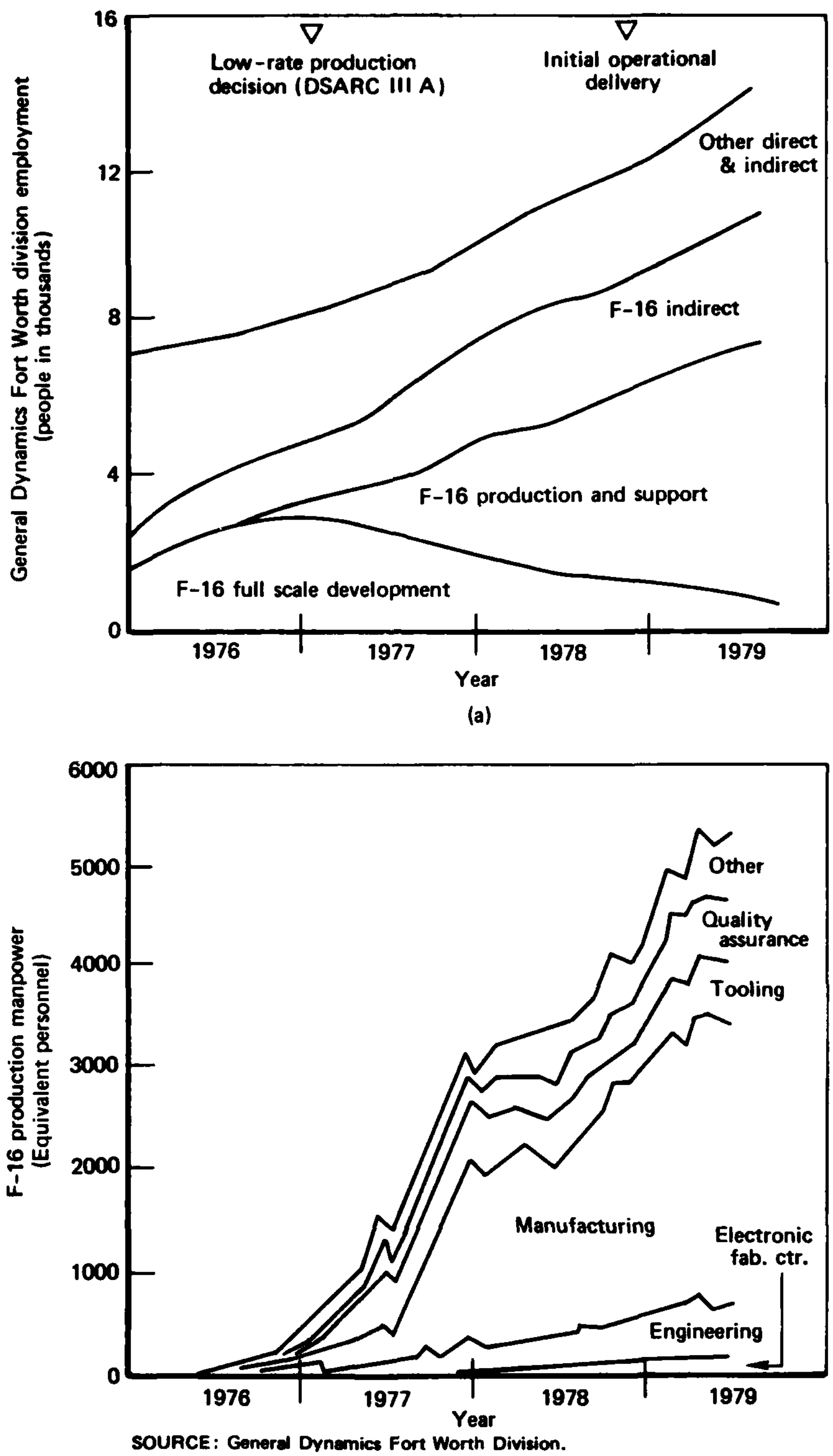
Differences in the scale of operation and the importance of job security are major reasons why most European manufacturing processes are more labor intensive than their American counterparts. The attendant workforce stability at times contributes to higher individual worker skill levels in Europe. European reliance on labor-intensive production methods, such as hand-insertion and manual soldering of electronic components, introduces difficulties into U.S.-European technology transfers (in both directions).

The F-16 program graphically portrays differences in the ability and willingness of U.S. and European firms to expand workforces in a short period. Even before official low-rate production approval, employment at General Dynamics climbed sharply (see Fig. 7). However, overall employment levels remained constant at SABCA, probably masking a concerted effort to realign workers internally. After initial production deliveries, SABCA's employment has risen about 20 percent along with that of General Dynamics.[17]

Policies with respect to holidays, vacation periods, and lengths of workweek also differ. One Roland contractor in the United States, for example, has estimated that its employees work 255 more hours per year than corresponding European employees, not including a substantially greater amount of sick leave frequently drawn by European employees. Production workers at some key European airframe and engine contractors work only a 37-hour week. Many European facilities shut down for as long as a month during the summer; others severely reduce output during July and August.

The desire for long-term workforce stability and the lack of significant flexibility and

[17]Given its present capitalization, managers and shareholders at SABCA favor a cautious approach, preferring to return ultimately to a more "normal" work force numbering about 1850. Germain Chambost, "The Belgian Aerospace Industry Today," *Interavia*, December 1979, pp. 1130-1131.



SOURCE: General Dynamics Fort Worth Division.

(b)

Fig. 7—General Dynamics Fort Worth division employment growth

expansion capability in Europe have important ramifications for programs involving U.S. and European industries. Dealing with differences in these areas is one of the most difficult program planning and execution challenges. How they have contributed to different U.S. and European program outcomes is discussed later in this section; problems in reconciling those differences are examined in Secs. III and IV.

DEFENSE ACQUISITION PROCESS

The scale differences and dissimilar workforce policies contribute to fairly large differences in the style and process of acquiring weapons. U.S. and European differences in operational requirements, development practices, and manufacturing methods can increase the length and the cost of technology transfer programs.

Requirements

Although the requirement for effective operation in a NATO scenario has strongly affected the design of U.S. military equipment, this alone has not insured a consonance of U.S. and European requirements for functional performance and weapon system support. Finding a way to accommodate differences in operational requirements is necessary in any collaborative program. The U.S. requirement for a worldwide deployment capability is perhaps the most important underlying source of many requirement differences. Worldwide deployment imposes a considerably more stringent set of requirements than those confronting our NATO allies, who are oriented primarily to deployment of their forces in Europe. The discussion below illustrates a few of the more important ramifications of the differences in requirements.

Functional Performance. Requirements of the United States include the need for deploying and operating in diverse theaters of operation. Range is of great importance for U.S. aircraft, whether it be derived from on-board fuel or from the ability to refuel in flight. Because fuel carriage requirements are an important aircraft sizing parameter, different range requirements can profoundly influence aircraft design, even if aircraft have similar performance requirements in the combat arena. Avionics suites may also differ to satisfy deployment navigation requirements. Strategic air mobility considerations may impose different sizing constraints on U.S. land vehicles. Extended deployments may also impose more stringent design requirements for resistance to the deleterious effects of shock, vibration, and salt air or water encountered during deployment.

U.S. aircraft and other equipment must be capable of operating reliably and effectively in temperature and humidity extremes not commonly found on the European landmass. Emerging U.S. emphasis on the capability to operate in austere environments in third-world areas may also contribute to different functional performance requirements (e.g., landing gear design, reliability standards).

Support. Experience gained from the U.S. Roland surface-to-air missile program has pointed out some differences in U.S. and European logistics concepts. Initial provisioning and replenishment of support items by the United States differ in that they are based on shelf life limitations, stock levels for use in the field, and mobilization requirements. European armies provision on the basis of yearly or multiyear requirements, but the United States relies on

inventory reorder points. Long shelf life requirements and worldwide depot stocking by the United States mandate more stringent materiel and packaging requirements.[18]

The proximity of European contractors to development, test, and deployment sites leads European services to rely more on high-echelon maintenance, emphasizing repair at the prime manufacturer or depot; U.S. worldwide commitments and deployment, as well as larger geographic size, lead U.S. services to use more field-level maintenance. American systems, their support equipment, maintenance manuals, and spares provisioning are all designed in line with the concept of making most repairs at the lowest practical level, often by military units themselves. This leads to a greater emphasis on built-in test equipment, to the use of more line replaceable units, and to a demand for higher levels of reliability. European services often place a lower priority on support equipment development because of the proximity of European contractors and operational forces.[19]

Design Methods and Manufacturing Techniques

Production scale, employee wage rates, worker skills, organizational and technical capabilities of contractors, and a weapon system's operational environment, among other factors, can all influence a contractor's design and manufacturing approach. Adapting a particular design and manufacturing approach to be consistent with that of other contractors or nations can require considerable effort. Failure to recognize these differences before a program gets underway can lead to difficulties.

Perhaps the overriding U.S. and European difference is the labor-intensive European manufacturing approach relative to the capital-intensive U.S. approach. European industry relies heavily on the skill of the individual worker, whereas U.S. contractors, which support higher production rates with a less skilled work force, rely more on mechanized means of production. For example, making the Roland producible using cost-effective U.S. manufacturing techniques required considerable effort. The typically lower scale of production in Europe and its skilled work force will probably continue to dictate labor-intensive production methods, but escalating hourly wage rates may in the future accelerate the introduction of more mechanized production techniques.[20]

European contractors in the Roland program have not emphasized the systems approach to the extent U.S. contractors typically do. There was no master document describing how the system worked, nor system functional schematic diagrams. To U.S. contractors accustomed to using such an approach, the absence of this information represented a key shortcoming in the body of technical data transferred from Europe.

The Roland program's U.S. contractors found a lack of standardization in drawing conventions from one contractor to another, which made the technology transfer much more difficult.[21] Frequently there were no indentured drawing lists describing the complete series of drawings required to manufacture an item.[22]

U.S. contractors also found troublesome a lack of standardization in the identification of

[18]U.S. Roland Program Management Office, *U.S. Roland Historical Report and Lessons Learned*, May 1977, p. 16.

[19]Ibid., p. 17.

[20]One sees evidence of this happening in the MRCA production program. German hourly wage rates are higher than those in Italy and Great Britain, and for that and other reasons they have begun to adopt a more automated production approach. "Tornado Production: Centralized Component Manufacture—Decentralized Final Assembly," *Interavia*, November 1977, pp. 1133-1135.

[21]The Roland program includes a number of the more prominent manufacturers of European equipment, however, including Aerospatiale, MBB, Thomson-CSF, Siemens, Telefunken, etc.

[22]However, translating technical documents caused little difficulty. During the technology transfer phase, over 4.2 million documents were translated at a cost of about $27 million.

parts on drawings. European contractors used their own in-house parts numbering systems. Frequently, there was no complete parts list for manufactured items. The European contractors had no counterpart for the U.S. contractor's component, materials, and parts organization. Designers picked their own parts, leading to a proliferation of different parts.

U.S. participants in the F-16, F-104, and Roland programs have also observed that configuration management and control are not always as well developed in Europe as in the United States. With a diversity of large and small contractors participating in the Roland program, this shortcoming led to manufacturing, testing, and inspection specifications that were at times inadequate, lacking altogether, or not accurately describing procedures used on the shop floor.[23]

In adapting the Roland design for U.S. production, Hughes found European manufacturers in some cases were less conservative in designing electronic equipment. For example, European contractors used components closer to their rated capacity than would U.S. contractors. Some line work on circuit boards of European design used closer spacing than U.S. boards (e.g., 1/12 in. instead of 1/10 in.). There was also more extensive use of commercial components.

U.S. contractors found that the original Roland was designed to less stringent reliability standards than current U.S. equipment. Reliability standards applied to the Roland design were equivalent to predecessors of current U.S. specifications. The fact that some of the U.S. standards were set up after the design of Roland was under way explains some of the differences. Other differences are attributable to the U.S. need for greater reliability because of its worldwide deployment requirements. Different U.S. and European safety standards contributed to a U.S. change in the ignition procedure for the Roland's boost motor. There was no direct European counterpart for U.S. standards for safe operation of equipment in electromagnetic fields. Such differences in standards also contribute to U.S. and European differences in testing, some of which are described below.

Testing

National differences in the rate, extent, and type of testing represent another area requiring possible accommodation in collaborative production programs. Different requirements for operating predominantly in a European environment, military design standards, and resources available for testing contribute to making the character of European and U.S. testing different. These differences are of greatest concern to the United States when technology is transferred from Europe, for additional testing may be necessary to assure that the technology can satisfy U.S. worldwide deployment requirements.[24]

Diverse climates, local geography, and location give U.S. test facilities certain advantages over European facilities. The United States can subject its systems to a wide diversity of environmental extremes and geographic conditions. Fair weather at a number of U.S. flight test facilities permits year-round flight operations. Airspace is less restricted at U.S. test locations than in more densely populated Europe. Test and evaluation teams have more latitude to test systems to their performance extremes under reasonably realistic conditions (e.g., tests against maneuvering high-speed targets) because of the sizable land and sea areas

[23]Richard N. Lawrence, *Cost Implications of International Technology Transfer Programs, Lessons from U.S. Roland* (n.d.), p. 6.

[24]The following examples are illustrative and do not extend to comparisons of subsystem test facilities such as engine test cells and wind tunnels.

of U.S. test ranges. The distance separating the United States from its adversaries also allows it to test the electronic countermeasure characteristics of its systems more freely. European developers must rely more on simulations because of the danger of compromising their ECM systems in open testing.

Differences in U.S. and European test environments and test requirements do not appear to result in systematic differences in the rate of accumulation of flight test hours. Comparing Figs. 8a and 8b, we see that the United States has demonstrated an ability to test military aircraft more intensively than European developers (e.g., the F-15 program and some others that preceded it); however, there is a similar rate of accumulation of flight test hours in a number of recent U.S. and European programs. The impressive rate in the F-15 program results from the use of far more test aircraft far earlier than in the typical European or U.S. program, whereas the A-10 and F-16 programs matched the flight test hour accumulations of most European programs during early testing by using only pairs of prototypes very intensively. The gross accumulation of flight test hours at initial operational delivery varies across U.S. and European systems, but no consistent trend of more accumulated hours for either U.S. or European aircraft development programs is discernible.[25]

The most direct comparisons of the quality and scope of U.S. and European testing come from the Roland experience, in which the U.S. Army program office tried to exploit the results of European missile testing to minimize the need for additional U.S. testing. American contractors found Europeans generally tested their missiles less stringently than U.S. requirements demand for several reasons, including some facility limitations and less diverse operating environments for European systems. Not surprisingly, three of the key items in U.S. testing of the system have been susceptibility to ECM, response to high acceleration targets, and supersonic tracking tests.[26]

American developers had to perform additional testing to climatic extremes—both tropical and arctic. The poorer condition of U.S. railroads also required more stringent rail impact testing. Testing for susceptibility to electromagnetic radiation was an area in which European testing did not begin to approach U.S. standards. Some European qualification test procedures differed markedly from U.S. procedures, although they were not necessarily always more or less stringent. In any case, U.S. and European differences with respect to test criteria have resulted in a sizable U.S. test program to evaluate the adequacy of the U.S. Roland system.

COMPARATIVE PROGRAM LENGTHS AND SCHEDULE SLIPPAGE

To formulate realistic and achievable schedules for the coproduction of weapon systems, the United States and its European allies will have to adjust to the underlying factors contributing to national differences in program length and performance in meeting schedule milestones. For example, if European subcontractors required more time for equivalent production activities than U.S. contractors in a collaborative venture, long lead activities to support European production might have to be moved ahead in the United States, perhaps increasing program risks by introducing greater concurrency of development and production.

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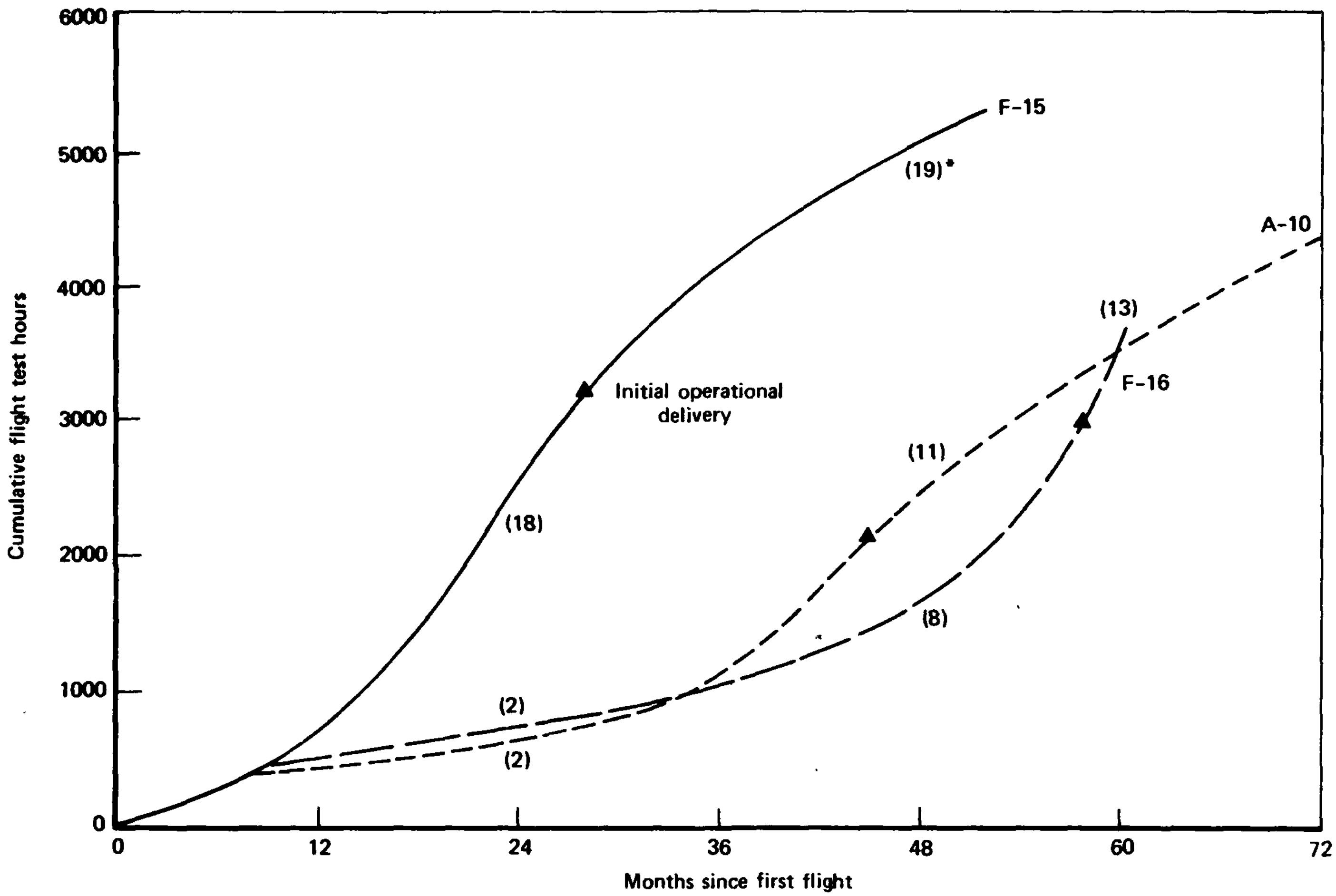
[25]See Table 8 below for comparisons of accumulated flight test hours at two program milestones, the initial production decision and the initial operational delivery. These kinds of comparisons, of course, indicate nothing about the kinds of information collected or how it is used.

[26]*U.S. Roland Coordinated Test Program III*, U.S. Roland Project Management Office, Report number ROL 2103-2, September 1979, p. 12.

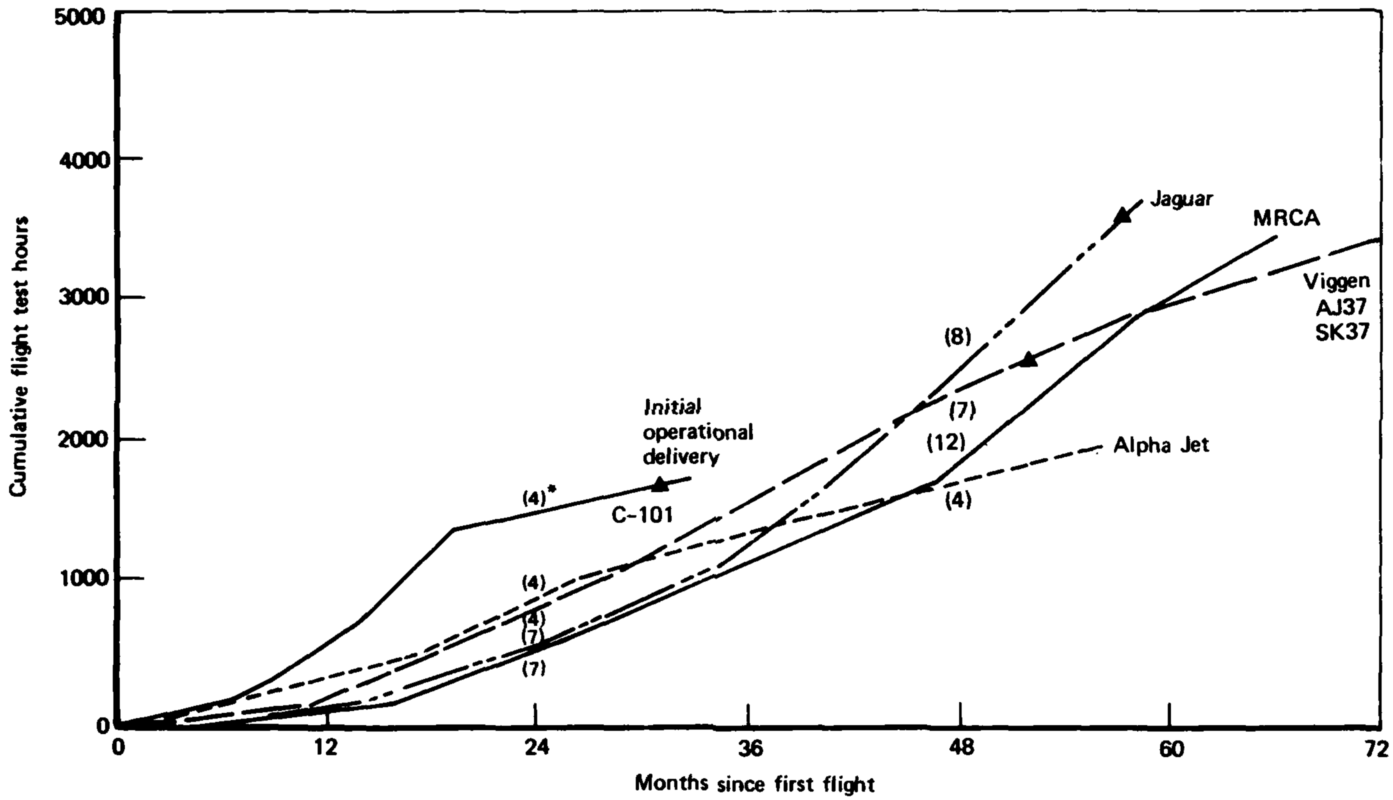


SOURCES:

A-10, F-15, F-16 System Program Offices, Air Force Test & Evaluation Center.

*Number of aircraft that contributed to accumulation of test hours

Fig. 8a—Intensity of U.S. flight testing



* Number of aircraft that contributed to accumulation of test hours.

Fig. 8b—Intensity of European flight testing

In short, accommodating differences in scheduling tendencies could require substantial changes in U.S. program schedules.

Comparison of U.S. and European military aircraft programs should quantify possible schedule differences and identify the factors contributing to the differences. Military aircraft programs are the basis for comparison, because they are important systems, accounting for a sizable fraction of NATO procurement budgets, their acquisition involves the breadth of U.S. and European aerospace industries, and a large body of literature documents their acquisition.

Comparison of Program Lengths

Comparison of program lengths can only broadly indicate national tendencies.[27] Moreover, program length by itself is not a good measure of program merit, for some expeditious U.S. programs have yielded equipment having major problems resulting directly from the rapid pace of development and production (e.g., F-111, C-5). Nonetheless, differences in average program intervals can signal differences in approach or style that can have implications for U.S. and European collaborative ventures.

We measure program length in terms of three acquisition intervals: (1) between design start and first flight, (2) between first flight and initial operational delivery, and their sum, (3) from design start to delivery. The first interval typically includes much of the substantive design activity in an aircraft program. The second includes flight testing, the transition from development to production, and the military service's preparation for receiving a new aircraft type. In the case of international collaboration during the production phase, U.S. and European differences after first flight are probably more important than differences before it because production collaboration frequently begins after first flight.[28]

We compared the acquisition intervals of 20 U.S. programs, 13 European national programs, and six European multinational programs (see Table 4) in three sequential steps, beginning with a simple comparison of average acquisition intervals for the three samples of programs to highlight apparent differences.[29] Then we compared individual programs to gauge the variability in acquisition intervals across programs. Finally, we performed statistical tests to measure the significance of apparent differences in the acquisition intervals of U.S. and European programs.

On average, U.S. programs took less time in each interval than the two classes of Euro-

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[27]We lack a common set of unambiguous events to serve as benchmarks for measuring program progress. Even such a seemingly distinct event as a first flight can have a very different meaning if one considers differences in the extent to which the first flight vehicle resembles a missionized aircraft.

[28]In selecting a design start date, we tried to identify when the government or governments involved made known to the airplane manufacturers their desire to have developed an airplane possessing a certain set of performance characteristics. In the United States, this generally corresponds to a request for proposal (RFP) for a contract definition phase or a prototype hardware demonstration phase. This definition or goal for identifying design start provided a starting point for trying to identify comparable benchmarks in other programs. To do so required making some subjective judgments.

Initial operational delivery is not necessarily the same as the first production aircraft delivery, because military services frequently use early production aircraft for testing. Using the date of initial operational delivery instead of the date of first production delivery includes the time the service uses to prepare for the acceptance and use of its first operational aircraft.

[29]Acquisition interval information was drawn from official U.S. program documents and open literature describing the history of aircraft developments in Europe and the United States. The sample includes aircraft of the size and general performance characteristics of aircraft that might be acquired collaboratively. This excluded such aircraft as the B-52 and C-5A, heavy long-range strategic aircraft. We also excluded the Harrier because of its unique development.

Table 4

AIRCRAFT PROGRAMS IN ACQUISITION INTERVAL DATA SAMPLE

European Programs		
Multinational	National	U.S. Programs
G.91	Buccaneer	F-100A
Atlantique	Andover C.Mk 1	F-101A
Transall	Belfast	F-102A
Jaguar	Nimrod	F-104A
Alpha Jet	Hawk	F-105A
MRCA (Tornado)	Mirage III	F-106A
	Mirage IV	F-8A
	Mirage F1	F-4A
	MB.326	F-111A
	G.222	F-14A
	MB.339	F-15A
	Viggen AJ-37	A-5A
	C-101	A-6A
		A-7A
		A-10A
		C-130A
		C-141A
		P-3A
		S-3A
		T-37A

pean programs—19 percent less time to reach first flight and 41 percent less time to reach first delivery (Table 5), although aircraft in the U.S. sample were generally faster, larger, and more technologically sophisticated than their European counterparts and designed to more demanding operational requirements. The most pronounced differences appear during the transition to production, when coproduction activities would usually begin. In terms of program length and the time from first flight to delivery, differences between the average acquisition intervals of European national and multinational programs are decidedly less pronounced than differences between acquisition intervals of U.S. and European national programs.

Simple averages mask large variations in acquisition intervals, particularly among the European programs (see Fig. 9 and the standard deviations in Table 5). The multinational programs have featured different levels of technical achievement and varying degrees of collaboration, including as many as three final assembly lines.[30] European national programs show an even greater variation in acquisition intervals and demonstrate how differences in acquisition approach can influence program lengths. For example, in the iterative development of the Mirage series of aircraft, prototyping allowed Dassault to achieve first flight rather quickly, but it took considerably longer to missionize the austere prototype configuration and make the transition to production. Conversely, in the Hawk trainer program, the British judged the technical risk to be low and elected at the outset to design and fly a near production-configured vehicle built on production tooling. This approach required more time to reach first flight but less time to make the first operational delivery.

[30]In Sec. III we consider the relationship between length and the level of collaboration.

Table 5

ACQUISITION INTERVALS FOR U.S. AND EUROPEAN PROGRAMS[a]

Program Type	Number of Programs	Mean Acquisition Interval (months): Design Start to First Flight	First Flight to Initial Operational Delivery	Design to Delivery	Standard Deviation (design to delivery in months)	Average Maximum Speed (km/h)	Average Empty Weight (kg)
European (aggregated)	19	42	49	91	25	1220	14000
Multinational	6	46	54	100	24	1180	12900
National	13	40	46	87	26	1240	14500
U.S. national	20	34	29	63	12	1540	14800

[a]Numbers may not add because of rounding.

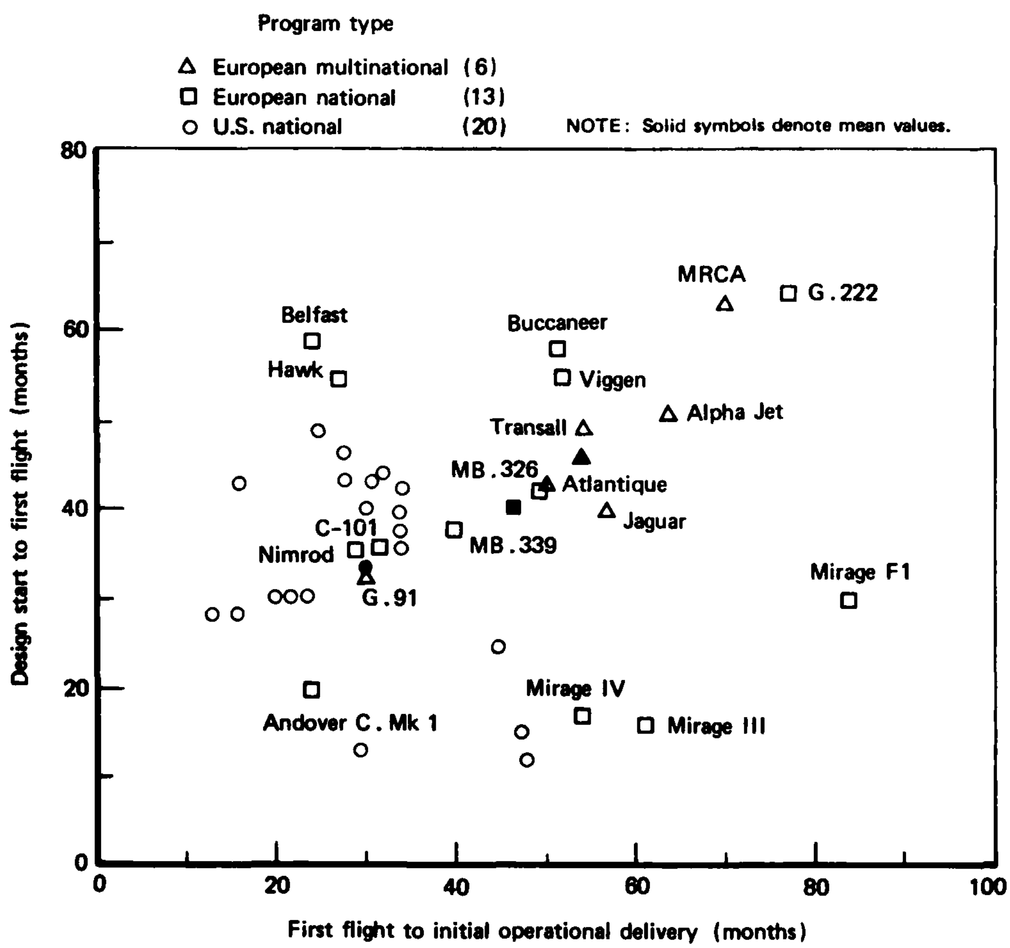

Fig. 9—Comparison of U.S. and European program lengths

The British and Italians, like the French with the Mirage, have also exploited existing designs to hasten the first flight of derivative aircraft (e.g., Andover C.Mk 1, Nimrod, MB.339).[31]

The considerable variability in acquisition intervals from program to program raises questions about the significance of the apparent differences in average U.S. and European acquisition intervals. By using two alternative statistical tests, we drew inferences about the significance of differences in mean program intervals.[32] Both techniques yielded similar results, depicted in Table 6. In each case, the smaller the value of the significance level, the stronger the evidence for the conclusion that the second type of program listed for each comparison tends to have longer acquisition intervals.[33]

These tests suggest that European programs tend to take more time than U.S. programs to proceed from first flight to initial operational delivery and from design to delivery. The evidence that European programs take longer to reach first flight is less persuasive, particularly considering the imprecision with which we can measure design start.[34] The evidence

Table 6

STATISTICAL SIGNIFICANCE OF DIFFERENCES IN U.S. AND EUROPEAN ACQUISITION INTERVALS[a]

	Upper Bound on Significance Level[b]		
Acquisition Interval	U.S. vs. All European Programs	U.S. vs. National European Programs	National European vs. Multinational European Programs
Design start to first flight	<.05 (.03)	<.25 (.14)	<.25 (.24)
First flight to initial operational delivery	<.0005 (.0005)	<.01 (.0075)	<.25 (.12)
Design to delivery	<.0005 (.0002)	<.005 (.0011)	<.25 (.13)

[a]Results computed using Welch's solution and the Wilcoxon rank sum statistic (in parentheses).

[b]The smaller the significance level, the stronger the evidence for rejecting the null hypothesis of no difference in acquisition intervals and accepting the alternative hypothesis that the second type of program listed for each comparison tends to have longer acquisition intervals.

[31]Depending on the extent of design modifications one could reasonably postulate that derivative aircraft pose less of a design task and hence require less time to reach first flight. The fact that all the European multinational aircraft in the sample but only seven of 13 European national aircraft can be classified as new designs may partly explain why the multinational programs took longer on average to reach first flight.

[32]Both techniques test whether the means of two samples (e.g., acquisition intervals of U.S. programs and national European programs) from two different populations are equal or whether one sample tends to have larger values (i.e., acquisition intervals) than the other. Making inferences like these when the variances of the populations are unknown is called the "Behrens-Fisher" problem. The first technique, Welch's solution, assumes the two populations are normally distributed, defines a test statistic, and approximates its distribution with an appropriate Student's t statistic.

The second technique, the Wilcoxon rank sum test, provides a distribution-free solution to the problem, because it does not assume normality of the two populations. It tests whether one sample is "stochastically larger" than the other, i.e., whether one sample of programs tends to have larger acquisition intervals than the other.

For details on the two techniques, see Peter J. Bickel and Kjell A. Doksum, *Mathematical Statistics: Basic Ideas and Selected Topics*, Holden-Day, 1977, pp. 219, 345-349.

[33]In other words, the smaller the number, the more likely a difference between the two types of programs.

[34]The same imprecision enters into the measurement of the interval from design start to initial delivery, but the imprecision is less important because of the greater length of that acquisition interval.

that collaborative European programs tend to take more time than national European programs is far from conclusive.[35]

The tendency toward different and longer program lengths in Europe seems to depend more on the European character of the programs than on whether they are multinational or national. Most previous research on collaboration has failed to acknowledge this, implying instead that most differences stem from inefficiencies introduced by collaboration.[36] A better understanding of the underlying reasons for the different schedule tendencies would permit more effective structuring of programs.

Comparison of Schedule Slippage

A second and perhaps more important dimension for measuring differences in U.S. and European scheduling tendencies is performance in meeting schedule milestones. Schedules can slip for many reasons (including externalities such as changes in national funding priorities) that may or may not reflect on the quality of program management, contractor capabilities, or the quality of the weapon system itself; hence one must avoid judging a program solely on the basis of schedule slippage. Whatever the causes, adjusting to unforeseen schedule slippage can be burdensome and costly for any program.

When schedules are changed or slip, costs can rise as capital investments optimized for a particular schedule are no longer optimum; overhead expenses can accumulate; older weapon systems may have to be refurbished if replacement deliveries lag, perhaps adversely affecting military capability. Changing employment commitments in response to schedule changes can also be costly, particularly in the European environment. Schedule slippage by one or several interdependent coproducers in an integrated coproduction program can seriously affect the continuity of production activities.

To identify differences between U.S. and European schedule slippage, we compared the schedule experience of several recent U.S. fighter and attack aircraft programs and several European multinational programs to see how well they met schedule expectations for first flight and initial operational delivery set at the time hardware development contracts were signed.[37] To the extent possible, we also tried to assess how much programs deviated from

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[35]Concern about the small sample size and the limited number of potentially meaningful explanatory variables for which data were available led us to rely primarily on Welch's solution and the Wilcoxon rank sum test rather than a more elegant multivariable regression treatment to discern differences in U.S. and European program intervals. Rudimentary multivariable regression analysis does, however, support the findings indicated by the other two methods.

That analysis included variables describing airplane characteristics (e.g., empty weight, maximum speed), program characteristics (e.g., U.S./European program, collaborative or national program), and contractor capabilities (e.g., production experience). After we controlled for aircraft size (using empty weight), and whether an aircraft was a new or derivative design, a dummy variable distinguishing between U.S. and European programs still proved to be significant in explaining differences in U.S. and European program lengths. Rudimentary measures of collaborative activity, such as a dummy variable distinguishing between national and collaborative programs, numbers of final assembly lines, etc., were decidedly less significant in explaining differences in program lengths, although the signs of the coefficients were intuitively satisfying—i.e., they indicated that collaboration tended to increase overall program lengths. In summary, the regression analysis indicated that European programs tend to take longer than U.S. programs even after differences in size and design lineage have been considered, and that rudimentary measures of collaboration were far less significant in explaining differences in program lengths. Further efforts to be more definitive by replacing the U.S./European program variable with a set of more descriptive variables quantifying U.S./European differences (e.g., program funding levels, number of test aircraft, initial production buy) were stymied by the unavailability of data across the programs surveyed.

[36]See the comparison of TOW and HOT missile program lengths made by Cohen (1978).

[37]For the U.S. programs, we used schedule expectations held at the start of full-scale development (the DSARC II decision milestone).

schedule during production by comparing slippage in deliveries of the last aircraft of the originally planned procurement (see Table 7).[38]

U.S. programs have generally come reasonably close to meeting first flight and initial delivery milestones, but pronounced schedule changes in U.S. programs have occurred during production, with cuts of 50 percent or more in planned peak production rates not uncommon (e.g., F-15). This schedule slippage is sometimes caused by continuing technical problems with the weapon system (e.g., F-111) or contractor difficulties in preparing for high rate production (e.g., A-10), but more frequently schedule changes are a product of the annual competition among programs for procurement funds in the budget process and cost growth of the weapon system (e.g., F-15). European officials suggest that their aircraft industries would find it almost impossible to adjust to the kinds of drastic production schedule changes characteristic of the U.S. acquisition process.

Some European programs have suffered considerably more slippage before initial deliveries than have U.S. programs, particularly in the time between first flight and first delivery. Once schedule slippage occurred in those European programs before first flight, it was not recovered by first delivery.[39] A U.S. program participant would have great difficulty accommodating to the two to three year slippage experienced during development in several of the European programs shown in Table 7.

Observations about the schedule stability of European programs after initial deliveries begin are more problematic, given the paucity of available official information on this subject. Such programs as the Atlantique essentially met production delivery schedules. Literature describing the Jaguar program suggests that the British portion of the production program accumulated no additional slippage after the initial operational delivery and indeed may have recovered some time. In contrast, the French have deliberately slowed deliveries of their Jaguars; hence, there has been considerable additional slippage since the initial operational delivery. As of early 1979, the MRCA production program was lagging six months or more behind schedule because of the need to make modifications identified during development flight testing.[40] More recent German funding problems may stretch production an additional year.[41]

European officials suggest that their government procurement agencies and legislative bodies are generally not inclined to make major changes in production programs once they are underway. Dutch, Belgian, and Italian officials cite the F-104G program, which, while having a rather turbulent delivery history, resulted in delivery of all aircraft within six

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[38]Because of the unofficial nature of the schedule information assembled for the European programs, comparisons made in Table 5 can only broadly indicate differences in U.S. and European tendencies in meeting schedule milestones. Moreover, the literature tends to give greater prominence to multinational European programs, so we can make only some limited observations about how well national European programs adhered to schedule.

[39]As best we can ascertain, some recent national European programs have experienced schedule slippage in planned first flight dates comparable to that experienced by the multinational programs shown in Table 7. For example, the Hawk, the MB.339, and the C-101 all flew on schedule or within roughly six months of planned first flight dates. Several national European programs have apparently not encountered as much schedule slippage as the multinational programs in reaching initial operational delivery. The first Hawk was delivered on time; the C-101 slipped by about six months. Reportedly, the French Mirage 2000 development program has thus far encountered a 6 to 12 month schedule delay. The initial operational delivery of the MB.339 did slip about two years, and the older Buccaneer program encountered slippage of more than two years.

[40]Klaus Regelin, "Mid-Point in the Tornado Program," *Interavia*, February 1979, pp. 136, 138. This delay is obviously relative to a timescale set down well after development began and does not reflect slippage relative to expectations held at the beginning of hardware development. Indeed, in its formative stage, the program was known as the MRCA-75, connoting planned mid-1975 deliveries to the German Air Force. See "The MRCA-75 Programme," *Interavia*, December 1968, p. 1471.

[41]"Germans Seek Tornado Program Stretch," *Aviation Week & Space Technology*, November 10, 1980, p. 23.

Table 7

ESTIMATES OF U.S. AND EUROPEAN TENDENCIES IN MEETING SCHEDULE MILESTONES

	Deviation from Scheduled First Flight		Deviation from Scheduled Initial Operational Delivery		Deviation from Scheduled Last Delivery	
Program	(Months)	Ratio of Actual to Planned	(Months)	Ratio of Actual to Planned	(Months)	Ratio of Actual to Planned
Atlantique	-1	.96	0	1.0	0	1.0
Transall	2	1.06	37	1.[illegible]1		
Jaguar	6	1.18	37	1.62	24/(64)[a]	1.2/(1.5)[b]
Alpha Jet	5-8	1.4-1.7	26	1.46		
MRCA	10	1.26	33	1.38		
F-111	0	1.0	8	1.16	(Reduced Procurement	
F-14	-1	.96	-1	.98	Quantities)	
A-10	2	1.09	1	1.03	(> 31)	(> 1.36)
F-15	0	1.0	0	1.0	(> 38)	(> 1.30)
F-16	0	1.0	0	1.0		
F-18	4	1.13				

SOURCES: Official program documents and various periodicals.

[a]Parenthetical values are projections for production that has yet to be completed.

[b]Multiple values for Jaguar refer to slippage in last delivery of British and French aircraft.

months of schedules laid down at the beginning of the program.[42] However, the French procurement of the Jaguar, German procurement of the MRCA, and Swedish procurement of the Viggen are exceptions to this generalization. The Swedish government has almost continuously reduced planned production rates and quantities of the Viggen since the start of the program.

To summarize, quantitative schedule information and qualitative observations made by European officials lead us to conclude that European military aircraft programs generally encounter larger and more frequent schedule slippage before initial operational deliveries than do U.S. programs. U.S. programs, however, experience schedule changes after deliveries begin that are similar in size to European slippage before initial deliveries. It is unclear whether European programs typically encounter schedule changes comparable to those made in U.S. programs during production. In any event, some significant differences in U.S. and European tendencies relative to meeting schedule milestones must be dealt with if collaboration between Europe and the United States is to be successful. The extent to which the differences are amenable to accommodation depends in large part on the factors contributing to the differences.

[42]Because it involved the licensed production of a U.S. design with the United States assisting in the technology transfer, the F-104G program is not perfectly comparable to the indigenous European aircraft programs illustrated in Table 7. We discuss the influence of collaboration on schedules in more detail in Sec. III.

Factors Contributing to Different Schedule Tendencies

Identifying differences in U.S. and European schedule tendencies is difficult. Definitively describing the causes of those differences is even more difficult. Nonetheless, it seems quite probable that differences in scale, workforce policies, and acquisition approach contribute in varying degrees to European programs being somewhat longer than U.S. programs, encountering more schedule slippage or changes during development, and perhaps experiencing somewhat less slippage or fewer schedule changes during production. One might reasonably expect that these same factors will to some extent shape the schedules of every collaborative program involving the United States and its European allies.[43]

Differences in U.S. and European workforce policies are readily apparent and documentable factors contributing to different U.S. and European scheduling tendencies.[44] Each of the workforce constraints noted below and common in Europe can contribute to increasing program lengths. The last three in particular can make the recovery of schedule slippage more difficult.

- More restrictive layoff policies.
- More liberal holiday and vacation policies.
- Shorter workweeks.
- More restrictions on hiring temporary labor.
- Preference for single shift operations.
- Preference for not using overtime.

On the positive side, recognition of these constraints can discourage governments from making wholesale schedule changes during the production phase that can frequently contribute to cost growth.

European contractors have difficulty in rapidly expanding or contracting work forces because of layoff restrictions and large fixed costs associated with a firm's number of employees. They prefer more extended schedules that maintain stable employment levels.[45] Differences in U.S. and European scheduling approaches brought about by different work force policies should be most apparent in those program phases in which U.S. contractors typically make their greatest labor inputs. This seems borne out by the acquisition interval and schedule slippage comparisons made earlier. The most appreciable U.S. and European differences occur between first flight and initial operational delivery, when manpower-intensive production operations typically get underway.

The European preference for single shift operations tends to lengthen the calendar time required for the accomplishment of program activities[46] and make it more difficult to recover schedule slippage. Since many design and engineering activities leading to first flight do not lend themselves to multiple shift operations to the extent that production activities do, we would expect the multiple shift policy differences to have the greatest effect on program phases after first flight. Different policies with respect to holidays, vacation periods, and

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[43]Factors uniquely associated with the act of collaboration that might have a considerable influence on program lengths or performance in meeting milestones are discussed in Sec. III.

[44]Recognizing that workforce policies can vary somewhat from one European country to another, we refer collectively to European workforce policies only for the convenience of the discussion.

[45]FRG contractors use large numbers of Italians, Romanians, and Turks, who generally bear the brunt of cutbacks when they occur, instead of the FRG union member. In this regard, at least, an FRG contractor may enjoy somewhat more flexibility than its European competitors. Covert (1979), p. 39.

[46]For examples in the context of a specific program—the F-16—see Sec. IV.

lengths of workweeks that contribute to lower facility and personnel utilization in Europe can also lengthen program intervals.

The size of a firm, the extent of the business opportunity, the nature of the production task, and the European country involved can influence the severity of the work force constraint. A firm having 30,000 employees has more opportunity to make intra-company transfers of workers to staff a new program than does a firm having only 2000 workers. Larger firms can also more easily use attrition as a means to reduce work forces. Likewise, attractive business opportunities can diminish employee and union resistance to some of the aforementioned workforce constraints. Nonetheless, these constraints remain a potent factor in shaping European program schedules.

Ascribing differences in program lengths or patterns of slippage to differences in governmental procedures or attitudes that indicate differences in acquisition approach is much more problematical. For example, there are alternative hypotheses as to whether differences in levels of competition in Europe and the United States can influence program lengths and slippage. The mergers described earlier have reduced the amount of intranational competition in Europe, particularly on the system or major subsystem level and to a lesser extent on the component level.[47] Even when there are multiple sources, governments may apply implicit or explicit pressure to favor one supplier over another in attempts to ease chronic unemployment in a particular region or to balance the distribution of work among contractors. In contrast, the Air Force Systems Command tends to use more competition in contracting.[48]

Advocates of competition usually argue for its use on cost grounds, although a logical extension of that argument is that a contractor functioning in a competitive environment will also seek to deliver its product quickly and on schedule to secure a competitive advantage. An alternative hypothesis asserts that competition can needlessly lengthen a program because of the comparative evaluation procedures and other management complexities on the buyer's side introduced by having to deal with more than one contractor.[49] Both schools of thought may have some merit. We cannot offer a definitive answer about the effect on program schedules of U.S. and European differences in the use of competition.

European programs have not usually featured the intensive progress measurement or program documentation of U.S. programs that focus attention on schedule performance. Program events are typically accomplished on a best-effort basis rather than through the use of contractual incentives geared to program milestones.[50] U.S. military services, however, frequently use incentive contracting. Monetary awards have induced U.S. contractors to make on-time deliveries, but those deliveries have sometimes been made at the expense of product quality.[51]

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[47]This is more a statement of the situation as it is today than it is a hypothesis for why various programs in the data sample have different acquisition intervals. For example, before the merger of Hawker-Siddeley and the British Aircraft Corporation, each submitted competing designs for what was ultimately to become the Hawk trainer aircraft. Two Franco-German teams submitted separate design proposals for what was to become the Alpha Jet. Wood (1976), p. 116; Terence Ford, "Franco-German Trainer/Light Strike Aircraft Projects," *Air Pictorial*, September 1970, p. 319.

[48]Of new contract dollars in FY 1979, 85 percent were let on a competitive basis, up from 66 percent in FY 1978. *AFSC Acquisition Initiative Update*, videotape by General Alton Slay, Commander, Air Force Systems Command, Summer 1980.

[49]These arguments are most frequently advanced in the context of competitive hardware demonstrations of major weapon systems in the United States, which rarely occur in a national context in Europe today.

[50]This observation is based on comments made by numerous European government and contractor officials; however, the literature does occasionally mention penalties or incentives. For example, production contracts in the Jaguar program had performance guarantees and penalties for late aircraft deliveries. Yates (1976), p. 42.

[51]The F-111 program offers a prime example, in which the first aircraft flew two weeks ahead of schedule (under flight restrictions) but suffered from major airframe and engine defects at that time. Knaack (1978), pp. 226-227.

Funding patterns, shaped partly by workforce constraints, may also contribute to differences in U.S. and European scheduling tendencies. European program schedules reflect a preference for funding continuity at lower rates for long periods of time to insure steady employment. The only available quantitative information is inconclusive (see Fig. 10), although various types of nonquantitative information lend support to the assertion. U.S. budgeting is done on an annual basis and schedules of U.S. programs frequently change during production as programs compete for resources. European programs are not immune to such changes, but European officials assert that their governments are generally less prone to

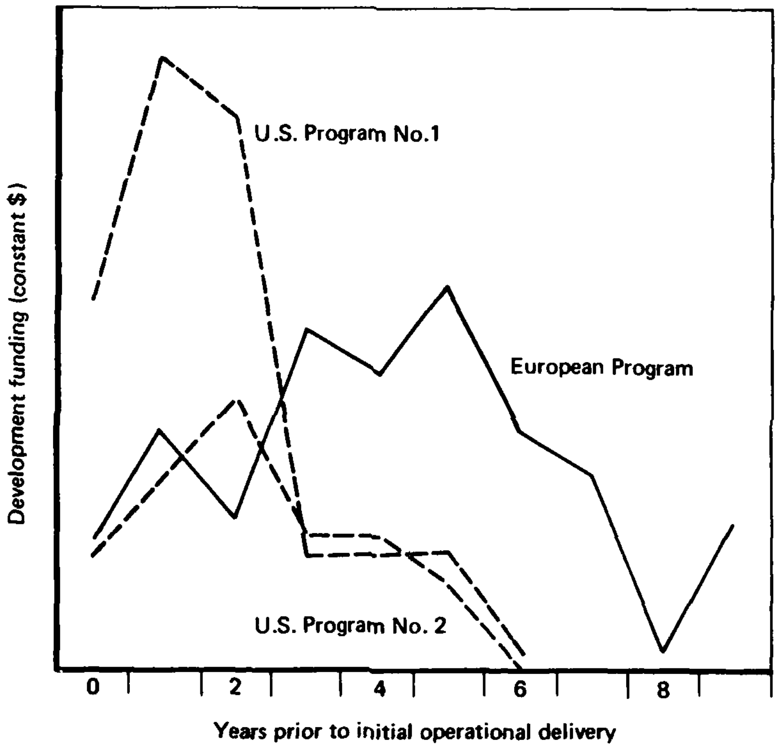

Fig. 10—Comparison of U.S. and European aircraft development funding profiles

alter funding profiles once production is underway. Multiyear budgeting practiced by the British in the Hawk trainer buy is one manifestation of this tendency.[52]

The Hawk program represents the antithesis of the more incremental risk-taking approach that characterizes many European programs. European contractors assert that their American counterparts go faster because they are more speculative and adventurous, taking a more aggressive investment approach because of the potential rewards from large American buys of equipment. They assert that more precontract work occurs in the United States than in Europe; hence by the time an RFP is issued, an American firm already has a head

[52]A fixed-price contract for 175 aircraft was signed 29 months before first flight. Wood (1976), p. 116.

start on a European firm.[53] In facing the prospect of much shorter production runs, European contractors have indicated they cannot afford to match U.S. levels of precontract investment.

The effect of different attitudes about concurrency and system maturity on schedules is somewhat unclear. A greater U.S. willingness to accept concurrent development and production might help explain the apparently shorter average U.S. time from first flight to delivery, since production activities might get underway before or shortly after first flight rather than after the accumulation of considerable flight test information. The F-111 and C-5A programs are extreme examples of this, in which the production commitment was made before first flight. More recently, the fly-before-buy principle has applied, although from Table 8 we see that the accumulation of flight test hours at the production decision has varied by a factor of ten. European programs also exhibit no consistent pattern. Accordingly, one cannot generalize about a stronger U.S. preference for concurrency being responsible for program length differences.

System immaturity in early equipment delivered to the field is a frequent by-product of concurrency. European government and contractor officials assert that although the United States delivers its aircraft more quickly, immature systems diminish their operational utili-

Table 8

INDICATORS OF CONCURRENCY/SYSTEM MATURITY IN U.S. AND EUROPEAN AIRCRAFT PROGRAMS

Aircraft	Time Between First Flight and Production Decision (Months)	Flight Test Hours Accumulated: At Initial Production Decision	Flight Test Hours Accumulated: At Initial Operational Delivery	Nature of Production Commitment
F-15	3	100	3200	Long lead production decision for first wing
A-10	26	700	2200	DSARC IIIA
F-16	36	1000	3300	DSARC IIIA
Jaguar	-8	0	3600	Production agreement signed by U.K. and France
Alpha Jet	23	800	>2000	Production tooling agreement signed by FRG and France
MRCA	23	500	>3400	U.K., FRG, Italy sign MOU for production of 40 aircraft
Viggen	13	250	2600	Swedish government orders 100 aircraft
Hawk	-29	0	?	U.K. government orders 175 aircraft
C-101	9	250	1600	Spanish Air Force orders 60 aircraft

SOURCES: Personal communication with Dale Randall, F-15 SPO, March 1978; *A-10 Initial Operational Test and Evaluation, Phase 2 Test Report*, Air Force Test and Evaluation Center, May 1976, pp. 11, E-1, E-2; personal communication with Lt. Col. Bogemann, A-10 SPO, August 1978; personal communication with Maj. Charles Core, F-16 SPO, January 1980; personal communication with Maj. Ronald Vraa, Air Force Test and Evaluation Center, January 1980; various periodicals.

[53]American contractors have made considerable preproposal investments, even in losing causes. In the 1969 F-X and 1970 A-X design competitions, individual contractors reportedly invested as much as 500,000 technical man-hours before issuance of the request for proposals.

ty, whereas the European military establishment is more willing to accept delays to get a mature product. However, if one considers flight test hours accumulated at delivery as one (imperfect) measure of system maturity, the differences are not that great between U.S. and European programs (Table 8).[54]

European aircraft have also been delivered with immature systems. The first 30 MRCAs, largely destined for training units, will reportedly not initially be cleared for cannon firing because of a vibration problem uncorrected at the scheduled delivery.[55] Some engine operating restrictions will also apparently be placed on early production aircraft to conserve engine life.[56] Conversely, the British Royal Air Force and the FRG Navy and Air Force did agree to MRCA delivery delays to make needed changes at the factory that were identified during development flight testing—indication of a willingness to slip schedules in the interests of system maturity.[57]

Roland program participants have suggested that the close proximity of the deployed weapon system to the factory may contribute to the fielding of less mature systems in Europe, since the contractor is nearby if trouble develops. Such a tendency might shorten European program lengths. Given the ambiguity of the evidence, it is unlikely that different preferences with respect to the maturity of equipment at delivery contribute in any major way to explaining differences in U.S. and European scheduling.

Some have asserted that less realistic scheduling has contributed to greater apparent slippage in European programs. The hypothesis is that resource constraints, particularly in the smaller European nations, make it impossible to budget for realistic production reserves. A propensity for unrealistic scheduling and an implicit acceptance of slippage by one collaborative program participant could become a critical concern if another participant placed more faith in the schedule and planned accordingly.

Unrealistic scheduling has apparently occurred in some European programs. Jaguar program participants expected to make their initial operational delivery some five years after the start of the program, which would have bettered the delivery time for the average European national program by 30 percent. Considering the complexity of the system and the complications added by the collaborative nature of the program, in retrospect this goal seems extremely ambitious, if not unrealistic. Similarly, during the MRCA design stage, program participants suggested making deliveries within six years (1975), more than one year less than the European national average. Program officials had amended this expectation by more than two years at the time of the first hardware contract, but even this revised target proved elusive. The Atlantique and Alpha Jet programs, in contrast, set schedule expectations about program length somewhat greater than the average for European national programs, although the Alpha Jet still encountered slippage relative to its operational delivery goal.

The United States has at times shown a willingness to allocate more resources for flight test aircraft, which can both shorten the time required to accumulate development test data and reduce the seriousness of losing an aircraft in a test program. With the exception of the MRCA program, which will ultimately have used 12 prototypes and six preseries aircraft

[54]Imperfect in the sense that we have no way of knowing whether there are differences in the amount of data collected per flight test hour, the systems for which data is collected, and the extent to which the developers use that data to mature the weapon system.

[55]Klaus Regelin, "Mid-point in the Tornado Program," *Interavia*, February 1979, p. 140.

[56]"R.B.199 is Europe's Biggest Engine Program," *Interavia*, February 1979, p. 146.

[57]"Germans Worried About Tornado Delivery Delay," *Aviation Week & Space Technology*, December 4, 1978, p. 20.

(introduced over a much greater time interval than in the F-15 flight test program), no recent European program has matched the 18 development test aircraft used in the F-15 program.[58] The Alpha Jet used only four prototypes and suffered delays directly traceable to the loss of a prototype and the subsequent temporary diversion of production aircraft to finish testing.[59]

Differences in scale can directly contribute to schedule tendencies in at least three important ways.[60] First, the greater industry-wide quantity of production in the United States may contribute to a generally more experienced industrial base adept at expediting production and meeting milestones. Second, longer and larger production runs offer more opportunities for learning and time-reducing capital investments; hence, the time required for individual production activities should generally be less than would be the case for European manufacturers producing in smaller quantities. Finally, a dominant U.S. manufacturer in the marketplace may profit from shorter material lead times than its smaller European competitors because of vendor priorities for volume purchasers.

Size and quality of facilities can also influence the time required to initiate and carry out production activities. In the F-16 program, U.S. facilities generally required less preparation to begin F-16 production.[61] Newly constructed or modernized facilities such as Fabrique Nationale's engine manufacturing plant near Liège and MBB's MRCA manufacturing facility in Augsburg may narrow differences in this area.

The larger pool of engineering and production personnel American firms can draw from may also contribute to different schedule tendencies. U.S. participants in the F-16 program have noted, for example, that the absence of a handful of key personnel at their European subcontractors could have a substantial schedule effect. These differences are smaller for large aerospace firms in the United Kingdom, France, or the FRG.

Managing these U.S.-European differences in a collaborative context introduces a set of important issues and implications relating not only to schedule but to cost and program management as well. For example, can one accommodate U.S. and European differences in a collaborative context without contradicting U.S. acquisition policy guidelines? What are the cost implications of duplicating manufacturing and assembly operations overseas? Does collaboration inevitably involve a time penalty? Section III addresses these issues.

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[58] "The Tornado Two Takes Off," *Air International*, November 1979, p. 219. Some U.S. programs that preceded the F-15 used more test aircraft. For example, the F-111 program used 23 RDT&E aircraft. Knaack (1978), p. 260.

[59] "Alpha Jet Development Phase Beginning," *Interavia*, August 1971, p. 957; "The Luftwaffe's Light Cavalry," *Interavia*, May 1978, p. 442.

[60] The discussion earlier in this section quantifies scale differences in a fiscal sense. The Section III analysis of third-country sales issues compares production output of fighter, attack, and trainer aircraft in terms of uni

[61] Section IV identifies other recurring production scale advantages enjoyed by General Dynamics in the F-16 program.

III. IMPLICATIONS OF U.S. AND EUROPEAN DIFFERENCES FOR MULTINATIONAL PRODUCTION COLLABORATION

The contrasts described in the previous section complicate every type of U.S.-European intergovernmental activity and most forms of transatlantic commercial activities. Production of a military aircraft system is an inherently complex undertaking; when the participating nations and industries have different and sometimes conflicting goals and practices, the endeavor is usually even more complex.

FACTORS INFLUENCING SCHEDULES IN COLLABORATIVE PROGRAMS

Seldom, if ever, does a collaborative program come about solely because two or more nations need a common piece of military equipment on which they can profitably collaborate. Rather, each participant usually enters the arrangement seeking to satisfy a diverse set of national objectives that are not necessarily compatible with those of the other participants. For example, in the MRCA program, all three participants needed an interdiction-strike aircraft, but the Germans needed theirs sooner than the others. The United Kingdom also needed an air defense interceptor, desired a strong industrial role for Rolls-Royce, and wanted to use the program to enhance relations with Germany and Italy before seeking formal admission to the European Common Market. Germany sought a substantial enhancement of its aircraft design, engineering, and project management capabilities; and all participants wanted to satisfy employment goals and to experience the benefits of working with the new technology in the system.[1] Many of the factors influencing schedules in collaborative programs stem from efforts to accommodate such diverse national objectives.

The activities that commonly hold potential for influencing schedules include:

- Adjusting to new program arrangements.
- Accommodating different configurations and standardization goals.
- Accommodating different delivery requirements.
- Making decisions using multinational committees.
- Distributing work among program participants.
- Reconciling different acquisition approaches.
- Scheduling for multiple integrated final assembly.
- Coping with political ramifications of altering programs.

Each factor can to some extent influence coproduction program schedules, although some are more relevant to programs involving codevelopment than those involving coproduction. We will note this distinction where appropriate.

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[1]Heath (1979), p. 334.

Adjusting to New Program Arrangements

Almost every collaborative military aircraft program has begun with the establishment of a new program arrangement, with all the administrative work required to formalize management procedures and the responsibilities and authority of each government and contractor program participant. Contractors then have to familiarize themselves with such factors as the contract law, accounting procedures, and design practices of their collaborators and establish successful working relationships with their counterparts in the other participating countries. Without a continuity of programs, much of the learning that takes place during a collaborative program is lost. Each new program requires an appreciable amount of front-end time to put together a new arrangement.

No multinational consortium has succeeded in selling a military aircraft design subsequent to the one that prompted the formation of the consortium in the first place, although Euromissile has successfully designed and marketed three missile types in a continuing arrangement between Messerschmitt-Bolkow-Blohm GmbH (MBB), Société Nationale Industrielle Aerospatiale (SNIAS), and the German and French governments.[2] Although we mention this factor largely in the context of codevelopment programs, it can play a role in coproduction programs as well. The loss of continuity at the conclusion of the licensed production of the F-104G in Europe forced the Dutch and Belgians to undergo a new learning process in organizing for the F-16 program.

The uncertainty surrounding the beginning of collaborative programs can actually extend far into a program. For example, in the Roland program, U.S. and European contractors signed industrial licensing agreements before source selection, at a time when the U.S. government had not made a clear declaration about acceptable royalty rates and payment schedules, data rights, third country sales rights, and other significant issues.[3] Later, the U.S. government insisted on eight significant changes to the basic license agreements, while the European governments requested one modest change. To some extent, the flow of documents from Europe to the United States early in the program slowed until negotiations among the three countries (the United States, France, Germany) could resolve the differences.[4] A suggestion has been offered from many quarters that it would be desirable for the DoD to issue guidelines on what constitutes an acceptable licensing agreement before licenses are negotiated. Another suggested solution is for intergovernmental MOUs to precede intercorporate license negotiations.[5]

Accommodating Different Configurations and Standardization Goals

Collaborative programs commonly involve the production of systems having different configurations to satisfy the needs of each participating country. Configuration differences can be pronounced, such as in the production of one- and two-seat aircraft variants or aircraft tailored to perform entirely different missions (e.g., air-to-air vs. air-to-ground), or more modest, such as in the addition of a drag chute, a different ECM suite, or the capability to launch

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[2]The Airbus Industrie consortium has succeeded in selling the A300 and its derivative, the A310, in the commercial market.

[3]Although a reversal from the F-16 approach, in which an intergovernmental MOU was signed before multinational industrial collaboration, the Roland situation is not necessarily atypical. U.S. and European manufacturers have signed similar agreements in preparation for upcoming U.S. Navy and Air Force aircraft trainer competitions.

[4]Malone (1980), pp. 46-47, 89.

[5]Ibid., p. 89; John H. Richardson, "Roland, A Technology Transfer Program," *Defense Systems Management Review*, Summer 1977, p. 14.

country-peculiar weapons.[6] *Production of systems having different configurations* can require additional tooling and fabrication and assembly procedures. Interleaving of systems having different configurations on assembly lines can reduce production learning and complicate the introduction of modifications on the assembly line.

Although a policy of standardization might act as a force for configuration stability, the resolution of standardization issues can become protracted, particularly when the participating governments differ in their perceptions of the threat, as was the case in the Roland program. When issues defied common resolution, the U.S. Army simply followed its own course. Reportedly, because European governments have not budgeted for standardization-driven changes, the consultation process has been made more difficult.

The absence of any stipulation about interchangeability requirements before contract award complicated the Roland program. Contractors drew up schedules and estimated costs assuming they would build a U.S. edition of Roland to U.S. standards and practices. Twenty days after the contract award, Congress directed that the program follow a policy of maximizing international interchangeability, forcing considerable revisions to cost and schedule estimates. *Not until nine months after contract* award had the term "interchangeability" even been satisfactorily defined.[7]

The Roland experience illustrates the desirability of the government specifying the type and degree of standardization being sought before a technology transfer program gets underway so contractors will not have to make costly changes in their approach. On an international level, an understanding among the program participants about the need to budget for standardization-driven changes might facilitate the resolution of standardization issues.

Accommodating Different Delivery Requirements

Frequently, to collaborate, one or more of the program participants has to adjust its preferred delivery dates. This factor played a role in the Jaguar codevelopment program, in which the British and French each changed their planned delivery dates by a year to narrow a three year difference in preferred delivery dates. On more than one occasion the United States has accelerated a program to meet the requirements of another collaborating nation. The F-16 schedule was compressed to accommodate Dutch and Belgian delivery requirements.[8] On the JP-233 Low Altitude Airfield Attack System program, the United States agreed with a British request to enter FSD even though the U.S. Air Force believed that additional project definition work was necessary.[9] Governments may also alter their procurement plans after programs get underway for budgetary or other reasons, in the process affecting the schedules of other collaborators in the program.[10]

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[6]The Jaguar program, which involved only two nations, featured the development of five variants, four of which were ultimately produced. Single and two-seat versions were produced for the French and Royal Air Forces, each having different equipment fits. A French Navy version never proceeded beyond the prototype stage. Yates (1976), p. 40. The more modest country-peculiar features are characteristic of the F-16 program. *Management Information Notebook*, F-16 System Program Office, various issues.

[7]The definition of international interchangeability agreed to by the United States, France, and Germany in the Roland program is: An item is internationally interchangeable if it is exchangeable in fit and function and retains the same performance it originally had. Variations in safety, reliability, maintainability, and other similar traits are allowed, however.

[8]The ramifications of this acceleration are discussed in Section IV.

[9]U.S. General Accounting Office, "U.S. Participation in the United Kingdom's Development of JP-233—A Costly Deviation from Acquisition Policy," B-200783 (MSAD-81-17), February 27, 1981, p. 2.

[10]The British, for example, had to adjust their schedules for production of Jaguar assemblies when the French government stretched out the procurement of its Jaguars. Another example is the NATO Hawk missile coproduction

Reconciliation of delivery dates can imply much more than just an apparent change in the date of receipt of the initial equipment. An acceleration of deliveries may introduce schedule risks, in that the phasing of certain development activities may be compressed or development and production activities may have to be concurrent.[11] An extension of equipment introduction dates may force a program participant to postpone planned aircraft retirements and instead institute life extension programs or, perhaps, buy interim aircraft.[12]

Making Decisions Using Multinational Committees

The multinational decisionmaking process inherent in collaboration has the potential for lengthening codevelopment or coproduction programs. It has clearly been a factor in the MRCA program, which has a complex framework consisting of a policy setting committee of government officials from the three participating countries, the NATO MRCA Management Organization (NAMMO), their contracting and management organization, the NATO MRCA Management Agency (NAMMA), and the industrial organizations of Panavia and Turbo-Union, which represent the system, airframe, and engine contractors in the three countries.[13] *Because program policy requires unanimity in decisionmaking by the Panavia partner* companies and the three governments represented in NAMMA, the governmental participants have had to resolve many disputes through three-way negotiations, thus exposing the program to a host of national influences. Numerous "program holds" have occurred as collaborators have struggled to negotiate disputes.

Slow decisionmaking has been common in coproduction programs involving the United States. On the NATO Hawk program, major decisions were to be made by a Board of Directors consisting of one high-level official from each of the participating governments. Because in practice the Board required unanimity for all decisions and met only every eight weeks, major decisions were often delayed. In addition, there were often difficulties in getting the five prime contractors to agree on matters such as planning of production schedules or even on whether to have any coordinated schedule planning. Decisionmaking by the industrial organization Société Européenne de Téléguidage (SETEL) was particularly protracted.[14] Similar problems occurred on the F-104 program. It has been reported that the inability of the government decisionmaking body to make prompt decisions jeopardized the entire production schedule. Only the German government's willingness to make substantial sacrifices kept the program going.[15]

The Atlantique program was a less complicated collaborative venture with more responsibility vested in a single government and contractor, and it encountered fewer schedule

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program, in which the French altered their purchase plans and necessitated a major program restructuring. See Cornell (1969), pp. 411-415.

[11]Early French delivery requirements in the Jaguar program brought about simultaneous airframe and engine development programs and concurrency of development and production activities. In this schedule framework, engine development problems contributed at least one year of schedule slippage. R. Salvy, "Jaguar Operational Soon," *Interavia*, December 1971, p. 1407. As discussed in Section IV, early delivery requirements also led to concurrency in the F-16 program.

[12]The Germans purchased F-4 aircraft to satisfy their interim requirements before MRCA deliveries, while the British have explored the option of recommissioning Lightning aircraft and equipping Hawk trainers with Sidewinder missiles to cope with delays in the delivery of the Air Defense Version (ADV) of the MRCA. Heath (1979), p. 336; "British Mull Tornado Program Change," *Aviation Week & Space Technology*, August 6, 1979, p. 17.

[13]Greenwood (1972), p. 9.

[14]Cornell (1969), pp. 379, 428-438.

[15]Ibid., pp. 537-539; Vandevanter (1974), p. 53.

delays arising from multinational decisionmaking.[16] The formal F-16 program arrangement does not require multinational unanimity in decisionmaking, although as a practical matter the program emphasis on multinational partnership and the political implications of making a decision without a consensus obviate some of the advantages of centralized U.S. management authority. Reportedly, issue resolution can be a protracted process because the Multinational Fighter Program Steering Committee and its subcommittees meet infrequently, forcing the System Program Director to work around problems until the committees resolve the issues.[17]

Some rationalization-standardization-interoperability (RSI) issues in the U.S. Roland program have simply defied resolution by multinational committee, forcing the United States in the interests of time to follow its own course of action. Clearly the nature of the program arrangement has much to do with the exposure to multinational decisionmaking delays—the greater the explicit or implicit need for unanimity, the greater the opportunity for delays.

Distributing Work

Perhaps the most vexing and time-consuming issue facing multinational committees is the distribution of the design, development, or production work, the means by which the individual program participants seek to achieve their diverse industrial and economic objectives. Delays can come from four sources: (1) difficulties in identifying qualified contractors; (2) difficulties in negotiating the distribution of work or work packages among the program participants to fulfill program objectives; (3) inefficiencies in design, development, or production introduced by collaborative work packages; and (4) the occasional need to transfer work across national boundaries to satisfy program equity considerations. The severity of the delays depend in great part on the program structure and the objectives of the program participants.

In the F-16 program, U.S. policy dictated an indigenous U.S. production capability for the entire system, with European contractors duplicating the production of certain items. However, because the European consortium countries did not all have well-developed aerospace industries, the process of identifying capable European contractors was particularly time consuming.[18] This process might be somewhat easier in programs involving larger European nations having more diverse aerospace industries.

The MRCA program, in which each government sought to acquire a full range of sophisticated technological expertise, is one of the more extreme examples of the conflict between efficiency and work sharing. Panavia, representing the MRCA industrial organizations, would solicit bids from firms in the three participating countries and select one on the basis of technical merit and cost. The government agency NAMMA could then veto or negotiate the Panavia recommendation if the quantity and quality of the distribution of work did not meet program objectives. Although reportedly NAMMA has seldom if ever exercised its veto power, the negotiation process has been extremely time consuming.

Frequently, the parties to the negotiations directed the selected bidder to collaborate with one of the losing bidders in another country. Implicit in this procedure is the use of contractors who in the original selection process were judged not to be competitive for cost or

[16]The French government acted for the other partner governments in placing contracts and Breguet Aviation of France had overall project control on the industrial side. Greenwood (1972), pp. 6, 7.

[17]U.S. General Accounting Office, *Status of the Air Force's F-16 Program*, PSAD-78-36, April 24, 1978, p. 2.

[18]Section IV discusses this in more detail, quantifying some of the delays.

other reasons. This kind of work sharing arrangement holds the potential for introducing delays because of the admission of less capable participants and the time required to establish and execute additional working relationships.

To compound some of the inherent inefficiencies of the work distribution process, work shares carefully negotiated on the basis of procurement value at the beginning of a program can subsequently get out of balance because predicted and actual levels of effort for particular tasks can differ and currency exchange rates can fluctuate. For example, to keep work shares balanced, Jaguar program participants had to shift production of the air intakes from France to Britain because the pound was devalued during the development phase.[19] Euromissile has reportedly encountered additional costs and delays for similar reasons.

As long as governments participating in collaborative programs are unwilling to waive their program shares in the interests of efficiency, then considerable negotiations will be necessary, for work distributions made on the basis of efficiency are unlikely to satisfy other program objectives. The greater the participants' demands to share in design, development, or production tasks across the spectrum of program activities, the greater the negotiating task, the greater the possibilities for production inefficiencies, and the greater the exposure to currency fluctuation difficulties.

Reconciling Different Acquisition Approaches

In dealing with the issue of how the work gets distributed, program participants must also reconcile or accommodate various governmental and industrial approaches for developing and producing equipment. This can require fundamental changes. For example, in the Jaguar program, the British cast aside the traditional development batch approach used on its previous national programs and adopted the French prototyping philosophy. Although the selection of a development approach could involve a contentious and protracted debate, on the Jaguar program both parties rapidly reached agreement.[20] British engineers and government officials had to quickly adapt to an unfamiliar approach, where the visibility, reporting, and control differed from what they were accustomed to.[21] The MRCA program represents the opposite extreme, in which the British accepted far more visibility, reporting, and control than in a typical national program.[22] European government and contractor officials involved in the F-16 program have had to make similar adjustments to satisfy extensive U.S. reporting procedures.

The process of accommodating different preferences with respect to timing of production commitments can also make the scheduling task more difficult, and at times can introduce delays. Most multinational program agreements have incorporated escape clauses, but commitments made upon entering collaborative programs, including those made at the outset to buy specific numbers of aircraft to establish work shares, more or less force the participating countries to continue in the program. This preempts certain traditional national prerogatives and calls for policy adjustments on the part of procurement authorities.

[19] Yates (1976), p. 38.

[20] Ironically, the addition of more aircraft variants after the program got underway, development delays, and the press for early French deliveries eventually so altered the program structure that it came to resemble the British development batch approach. Skeptics might use this fact to advance the notion that the apparent British compromise on development approach was more one of form than substance; however, none of the available literature seems to suggest anything other than an earnest British effort. Yates (1976), p. 42.

[21] Ibid., pp. 37-39.

[22] Heath (1979), p. 342.

Although initial program agreements make it unlikely that a country would not begin production, national differences about the appropriate time to fund production activities have contributed to sizable delays in at least one collaborative program, the French/German Alpha Jet. The French normally launch the tooling and production phase after the maiden flight of the prototype, with the prime contractor and government agencies both recognizing that prices quoted at that time might change somewhat as specifications mature. The Germans, unwilling to take this kind of risk, insisted on frozen specifications before launching production, an assurance the French prime contractor Dassault could not provide at the time of first flight. Eventually the Alpha Jet underwent two years of additional testing before the start of production to satisfy German concerns and to enable Dassault to commit itself to a set of specifications. Reconciling different risk-taking philosophies can have a considerable schedule effect, although an effect is more likely in programs featuring codevelopment.

Scheduling for Multiple Integrated Final Assembly Lines

Several collaborative programs, including the F-104, Alpha Jet, NATO Hawk, Jaguar, MRCA, and F-16 have used multiple final assembly lines integrating major components manufactured at separate locations. Such an arrangement can introduce a number of scheduling difficulties not present in a program with a single assembly line (the typical national program). Usually, one gives up flexibility, but redundant production capability also increases program flexibility in the event that one facility encounters difficulties. U.S. production assistance in the F-104G licensing program helped Europeans overcome startup difficulties such that final deliveries occurred within six months of schedule over four to six year production programs (see Table 9); a similar situation occurred in the NATO Hawk program.

In the F-16 coproduction program the United States demonstrated a willingness to pay

Table 9

SCHEDULE EXPERIENCE IN THE F-104G PROGRAM

Location of Production Line	Contract Award to Initial Delivery (Months)		Contract Award to Final Delivery (Months)	
	Planned	Slip	Planned	Slip
Belgium	23	0	60	6
FRG	31	5	72	6
Italy	18	1	51	2
Netherlands	24	0	59	3

SOURCES: Carter (1974), pp. 20-54; "Evolution of the F-104G Starfighter," Lockheed-California Company news release (undated); C. Brownlow, "F-104G Consortium Struggles to Overcome Difficulties in Management," *Aviation Week & Space Technology*, August 6, 1962; "This Week Marks 10th Birthday of World Wide F-104 Program," *Lockheed Star*, March 20, 1969, p. 4; personal communication with Crawford Brubaker, Director, International Marketing, Lockheed Corporation, July 1978; letter from A. W. White, ASW Export Sales, Lockheed-California Company, July 1978; "The F-104G Starfighter Program," NASPO (undated).

for redundancy in production as insurance against excessive delays. That policy has already helped compensate for early production difficulties experienced by some European subcontractors.[23] Factors brought about by collaboration can at the very least complicate the scheduling task and at worst cause programs to take longer or schedules to slip, but American industry can provide a certain degree of insulation against exposure to the deleterious effects of these factors. Most European programs have not used the F-16 program's level of redundancy and hence have had more exposure to schedule delays.

Having multiple integrated assembly lines can make it difficult to incorporate modifications or to adjust for delays in production activities in a timely manner. Some work packages cannot be completed in parallel if production lags, as might be possible with a single assembly line. An MRCA forward fuselage being assembled at British Aerospace in Warton, U.K., for example, must be completely finished prior to its being shipped to Manching, FRG, for integration with remaining airframe components.[24] The serial production constraint makes it more difficult to accomplish production activities concurrently; hence, the time required to assemble and deliver an aircraft may exceed that of a single national production line.[25]

Assembling in multiple locations may also increase schedule disruptions caused by work stoppages. Unless program participants are willing to build up large reserve inventories of parts to support each assembly line, multiple assembly lines will tend to dilute the spare parts buffer at any given location. According to contractor officials, F-16 program planning calls for sizable buffers of airframe parts at some additional inventory cost to guard against this circumstance.

Assembling aircraft in multiple locations, rather than on a single assembly line, may also diminish learning opportunities, which can result in increased levels of effort. Whether that then results in a sizable schedule penalty or increased cost depends on the manning and scheduling policies adopted by the producer, as well as the complexity of the assembly task itself.

Coping with Political Ramifications of Altering Programs

Each of the aforementioned factors generally alters program schedules. In contrast, the political nature of military collaborative aircraft program arrangements can make programs somewhat immune to changes they might not enjoy in a national context. Several collaborative programs have suffered cancellation—the Anglo-French Variable Geometry aircraft program, the MBT-70 tank, and the Advanced Vertical/Short Takeoff and Landing aircraft program are some prominent examples. Other collaborative programs have encountered considerable difficulties during development but avoided cancellation. The Jaguar program lost one prototype in a crash, had another severely damaged by an engine explosion on the ground, and had a third lose its undercarriage in still another flight test accident; but development went resolutely forward. One can only speculate about the fate of a U.S. aircraft program encountering similar adversity.

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[23] See Section IV for more details.

[24] "Germans Worried About Tornado Delivery Delay," *Aviation Week & Space Technology*, December 4, 1978, p. 20.

[25] Airbus program officials have demonstrated an apparent greater willingness to overcome this sort of problem than have military program officials. For example, the Airbus consortium has shipped British-manufactured A300 wings to Toulouse, France, before the completion of equipment installation to keep to schedule. It then temporarily transfers British workers to Toulouse to complete the equipment installation task concurrent with the beginning of final assembly operations.

Collaborative programs frequently exhibit a resistance to schedule alterations brought about by reductions in procurement quantities. Subsequent to the G.91 and Atlantique programs, which lacked substantial penalties for outright withdrawals or reductions in procurement quantities, participating governments in collaborative military aircraft programs have not reduced planned procurement quantities, although they have at times attempted to do so and have extended procurement schedules.[26] In exchange for this stability, program participants give up some flexibility.

Influence of Collaboration on Program Lengths

Comparisons made in Section II illustrated the inconclusiveness of evidence that European collaborative programs tend to take longer than European national programs. To make some very limited observations about multinational program lengths, we developed a rudimentary characterization of the level of collaboration in each program and considered the sensitivity of the results to the exclusion of particular aircraft programs. Figure 11 identifies five major phases in the acquisition of military aircraft weapon systems and notes those phases that featured multinational involvement for six collaborative programs, each of which included multinational involvement in the requirements phase.[27]

The multinational programs that involved more extensive collaboration had somewhat longer program intervals. The MRCA program includes the greatest degree of collaboration and it has the longest program interval.[28] The two programs that did not feature collaborative design took less time than those that did. These same two programs also initially used single production lines, although somewhat later the Germans established a second G.91 production line.[29] Each collaborative program featured new aircraft designs, adding to the development task, whereas slightly less than half of the European national programs in our sample enjoyed the advantage of having some antecedent prototype or production flight hardware.

Critics of collaboration often use the MRCA program as an example of the time penalty associated with collaboration. Defenders of the program have suggested that the protracted time to accomplish first delivery may be a one-time phenomenon that would not recur in a subsequent development by an established Panavia organization. The German use of the MRCA program as a means of enhancing its aircraft design, engineering, and project management capabilities, the time required to establish Panavia as a working organization, and the learning process that Panavia inevitably had to go through are frequently cited as lengthening the program. Thus, it is possible that the MRCA acquisition program is atypical, and

[26]The German government wanted to reduce its Transall tactical transport aircraft buy from 110 to 90 aircraft because of financial difficulties and a desire to purchase more helicopters, but intense French protests that such a move would increase their costs persuaded the Germans to abandon their plans. Michael Wilson, "Transall C-160, An Exercise in Multinational Transport Design," *Flight International*, April 25, 1968, pp. 616, 617.

[27]National programs that were collaborative in the sense of using international subcontracting for design, development, or production tasks are excluded (e.g., Northrop and MBB commercial subcontracting involvement in the design and development of the C-101 trainer for the Spanish firm CASA).

[28]For example, for the Interdiction Strike version of the MRCA, the majority of the avionics equipment was codeveloped and coproduced on a multinational basis. In contrast, although the Jaguar airframe and engines were the product of codevelopment and coproduction, Britain and France separately produced many key avionics systems for their own aircraft. "The Jaguar in Detail," *Interavia*, June 1968, p. 756; "The Panavia 200 Multi-Role Combat Aircraft," *International Defense Review*, April 1974, pp. 453-454; Heath (1979), p. 334.

[29]The G.91 program did not feature integrated production and assembly to the degree some of the other programs did. Aeritalia (Fiat at that time) provided some early support to help establish German production, and also manufactured equipment like external tanks, but there was not a substantial interchange of parts (hence the treatment of the G.91 assembly block in Fig. 11). Personal communication with General Giancarlo Ortenzi, Aeritalia, December 1978.

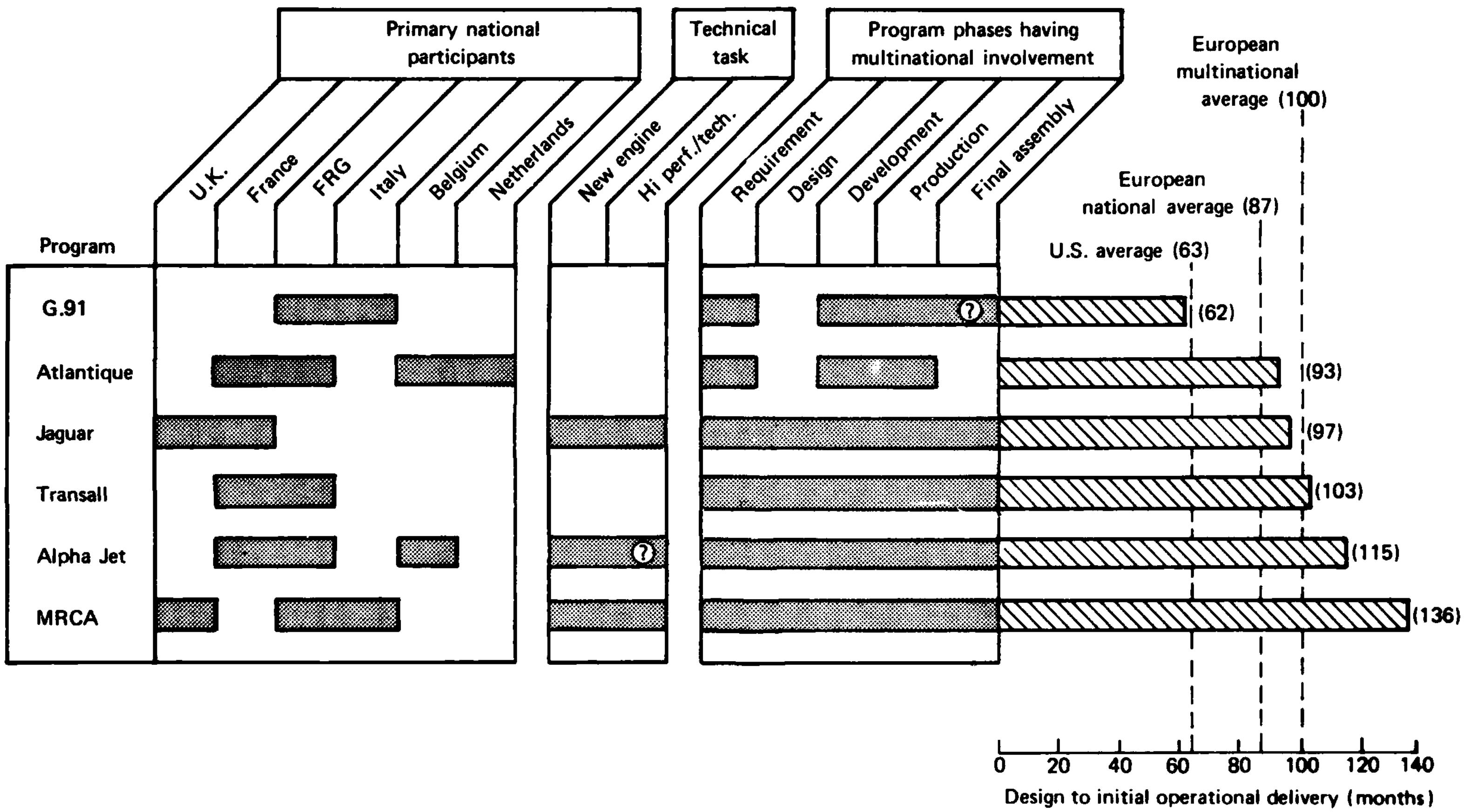

Fig. 11—Measures of collaboration

its length will not be a good indicator of the time required to collaborate on a future aircraft (in the context of the Panavia consortium).

The time penalty question cannot be addressed in a quantitatively satisfying manner because the empirical sample of programs is simply too small. We will illustrate by somewhat arbitrarily excluding first one and then another program from the sample and showing how the results can drive one to form different and opposite conclusions.

To consider the point of view that the MRCA program is atypical, we discarded it from the multinational sample and reassessed acquisition interval differences. To cover the other extreme, we evaluated a case that excluded the G.91 program, which some might argue either did not include a level of collaboration comparable to that of the other five aircraft in the sample or featured collaboration that began too late to influence the time required to make initial deliveries.[30]

Excluding the lengthy MRCA program halves the difference between program lengths of European national and multinational programs, and excluding the G.91 program sharpens the apparent differences (see Table 10). Excluding both does not appreciably change the mean program intervals. Differences in European national and multinational program lengths are not statistically significant when the MRCA is excluded (see Table 11).[31] Distinctions sharpen when the G.91 is excluded. The considerable sensitivity of the results to these somewhat arbitrary exclusions illustrates the lack of an adequate empirical foundation from which one can make quantitatively satisfying arguments about the effect of collaboration on military aircraft program lengths, nor is there sufficient evidence to determine whether licensing a European design for production in the United States saves time; it is clear, however, that those programs do have schedule considerations uncharacteristic of domestic programs. The U.S. Roland program illustrates that some of the factors that complicate other collaborative arrangements are not as much of an issue when technology is transferred to the United States.[32] Roland program agreements call for the European manufacturer, Euromissile, to provide U.S. contractors with sufficient information to produce the Roland system in the United States. With only a few exceptions brought about largely by economic considerations, the transfer is basically one of information, not hardware.[33] There is no two-way interchange of manufactured items like the one in the F-16 program. U.S. contractors do not support European production lines, so the difficult scheduling problems posed by multiple integrated final assembly are not a complicating factor. Owing to the program structure, the burdensome distribution of work discussed earlier has also not been a factor in the program. These features freed the program from some scheduling difficulties encountered in other collaborative frameworks, but a policy requirement to maximize the interchangeability of U.S. and European Roland components introduced additional complications.

Most comparisons indicate that the U.S. Army has saved some development time by adapting an existing European design. Hughes Aircraft, the U.S. prime contractor for Roland, has estimated that to indigenously develop a missile system having a capability comparable to Roland would have required an RDT&E program lasting about nine and one-half years, more than three years longer than the expected duration of Roland's Technology

[30]Flight of the first German-assembled aircraft occurred approximately two years after Italian aircraft began to enter squadron service. J. W. Taylor (ed.), *Jane's All the World's Aircraft*, 1965-66, p. 68.

[31]Reflecting a judgment that differences having significance levels below about .05 or .10 are not very significant.

[32]For more details on Roland, see Malone (1980).

[33]Some connectors, castings, etc. are being procured directly from Europe because the limited quantities of some items required to produce the U.S. Roland system did not justify the tooling costs to establish U.S. production capabilities. Euromissile also provided missiles for testing and will manufacture the Organizational Maintenance Test Set. Lawrence (n.d.).

Table 10

COMPARISON OF ACQUISITION INTERVALS FOR EUROPEAN NATIONAL AND MULTINATIONAL PROGRAMS

Program Type	Number of Programs	Mean Acquisition Interval[a] (Months): Design Start to First Flight	First Flight to Initial Operational Delivery	Design to Delivery
European national	13	40	46	87
Multinational				
Complete sample	6	46	54	100
Exclude MRCA	5	43	51	94
Exclude G.91	5	49	59	108
Exclude MRCA, G.91	4	46	56	102

[a]Numbers in rows may not add because of rounding.

Table 11

STATISTICAL SIGNIFICANCE OF DIFFERENCES IN EUROPEAN NATIONAL AND MULTINATIONAL PROGRAM INTERVALS

Acquisition Interval	Upper Bound on Significance Level[a]: European National versus Multinational	European National versus Multinational (Excl. MRCA)	European National versus Multinational (Excl. G.91)
Design start to first flight	<.25[b]	<.40	<.25
First flight to initial operational delivery	<.25	<.40	<.10
Design to delivery	<.25	<.40	<.05

[a]The smaller the significance level, the stronger the evidence for rejecting the null hypothesis of no difference in acquisition intervals and accepting the alternative hypothesis that the second type of program listed for each comparison tends to have longer acquisition intervals.

[b]Results computed using Welch's solution.

Transfer, Fabrication and Test (TTF&T) phase.[34] Contractor responses to a 1970 RFP for the Low Altitude Field Army Air Defense System estimated development times of 11 years, in contrast to U.S. Roland's six years.[35] The Patriot, admittedly a larger, more complex Army surface-to-air missile, has undergone at least eight years of full-scale engineering development, preceded by five years of advanced development. Although these comparisons suggest some development time savings, the extent of the savings, if any, in other programs, would depend on a host of factors, such as the maturity of the design at technology transfer, the degree of adaptation demanded by the American recipient of the system, and international standardization goals.

Influence of Collaboration on Schedule Slippage

Striking contrasts between the magnitude or pattern of slippage in European national and collaborative programs are not evident. Experience accumulated in the European collaborative programs does, however, permit some limited observations. National and multinational program schedules have both slipped because of technical problems, test accidents, funding perturbations, strikes, bankruptcies, etc., but collaboration introduces other factors that can influence schedules (e.g., the process of distributing work).

Do features of collaborative programs cause scheduling problems to occur more frequently than they do in national programs? To the extent that collaborative programs embrace new aircraft designs to satisfy multinational requirements in preference to derivative designs, they may be more generally exposed to the full range of development problem possibilities. Moreover, greater numbers of participants may increase the likelihood of a funding problem, requirement change, work stoppage, or bankruptcy adversely influencing the program schedule.

Once schedule problems occur, is it harder to resolve them in the multinational context? That would depend on the program structure, the situation, and the spirit of cooperation among the participants. Requirements for unanimous decisions have contributed to delays in resolving problems in some programs, such as the NATO Hawk or MRCA.

Does collaboration with U.S. involvement alter the probability of encountering program slippage? The answer depends on the nature of the collaborative arrangement, but the greater scale of production, the flexibility of work forces, and a mature, diverse production base should enhance the ability of U.S. contractors to recover from schedule slippage. Past and present U.S.-European production collaboration experiences support this contention.

COST IMPLICATIONS

The cost implications of coproduction depend on one's perspective. For example, total program costs can increase if an extra participant in the production process introduces inefficiencies, but each participating nation might benefit by sharing costs. Although one can estimate the cost effects of coproduction from either perspective with a fair degree of accuracy when specific program details are known,[36] there is no general framework for considering potential effects on cost. This subsection provides such a framework.

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[34] "U.S. Roland, A View of the Program from Today's Vantage Point," briefing by Ken Borsch, Hughes Aircraft Corporation, October 1979.

[35] Malone (1980), p. 77.

[36] See Section IV, which discusses the F-16 coproduction program, for an illustration.

The framework has two basic parts, representing the two major categories of potential coproduction cost effects. The first covers costs incurred in the technology transfer process that mainly occurs before production activities get underway. The second addresses the prospect of inefficiencies resulting from duplication of production effort.

Transferring Technology

All coproduction arrangements involve transfers of technology, a term used here broadly to include all activities associated with enabling a nation to produce a foreign design. This process usually has minor and straightforward cost consequences for the licensor, who generally receives a license fee (or royalty) to compensate for the costs of transferring the necessary drawings and expertise and for the production rights themselves.[37] From the licensee's standpoint, the cost consequences can be substantial.

The basic formula for ascertaining the net effect of a technology transfer is the forgone development costs less the costs of obtaining the data and making the preparations necessary to produce the item.[38] Estimating forgone development costs, though necessary, is an exceedingly speculative activity that was not undertaken by this study. Instead, the following discussion investigates the cost of technology transfer, drawing primarily on the Roland program.[39]

Components of Technology Transfer Cost. On the surface, the cost of acquiring technology for production is the contractual license fees, or royalties. These fees generally cover acquisition of technical data, some engineering assistance, and the production rights. However, they are a small fraction of costs incurred by the transferee in preparing for full-scale production of the licensed item. Remaining costs generally fall into five categories; (1) data transfer, (2) design adaptation due to requirements differences, (3) parts selection and qualification, (4) changes due to differences in manufacturing methods, and (5) testing.

A consideration that affects all of these costs, of course, is the degree of standardization sought by the nations involved. At one extreme, the transferee can strive for an exact copy of the original design, requiring identical piece-parts and configurations. Many programs aim for interchangeability at the component level, which permits some internal differences.[40] When design changes are made to accommodate various operational, support, and manufacturing concepts, maintaining even a modest amount of interchangeability can be difficult without substantial additional cost.

Potential licensors have historically provided very limited data on the system of interest before a license agreement is signed. Their restraint stems largely from a concern that premature disclosure could enable the potential licensee to produce an improved version of the design without formally entering into a license arrangement. European licensors have

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[37]An exception occurs when the transferor, or licensor, purchases the item after it is produced by the transferee. In this case the question of whether the purchase price is higher than it would have been without coproduction becomes relevant. Another exception occurs when the transferor's own production lines support those of the transferees. Then one should consider whether the transferor receives any benefits from the additional production (and perhaps whether the foreign commitments affect the ability of the transferor's industries to support their nation's needs in a timely fashion). The F-16 discussion in Section IV provides an illustration.

[38]An exhaustive analysis ought to consider several other factors, such as the effect on indigenous design capabilities. In many cases, forgone development costs are likely to be irrelevant, as when a nation is technologically incapable of designing and developing a comparable item.

[39]Other programs reviewed included the B-57, the WM/22 naval gun, the Ratac ground surveillance radar, and the Harrier V/STOL strike fighter.

[40]The component may be a line replaceable unit (LRU), such as a computer, or a shop replaceable unit (SRU), such as a printed circuit board, which is identical in form, fit, and function, despite using different parts.

generally tried to provide American licensees enough data to enter a paper design competition and make preliminary cost estimates, but not enough to produce the design. Such samples of technical data—usually of block diagrams and functional descriptions—rarely reflect the quality and size of the entire data package. This led U.S. contractors to significantly underestimate the technology transfer task and incorrectly gauge the maturity of the Roland design. Original Roland program plans called for about 25,000 documents to be delivered within 30 days; in all, the process involved about six times as many documents—many delivered out of sequence—and took well over four years to complete (see Fig. 12).[41] Receipt, translation and conversion, duplication, storage, and distribution can involve a sizable cost. For example, because complete Indentured Drawing Lists (IDL) are usually not compiled in Europe until production is well underway, this step may have to be accomplished by the U.S. licensee. When it involves extensive visits to European contractors and their subcontractors, this becomes a sizable job.

A second cost category includes design changes required by different U.S. and European operational requirements. These changes often reflect more stringent U.S. safety standards, broader deployment and use plans, and different perceptions of the threat. In this sense, the Roland missile system development was inevitably viewed as incomplete from a U.S. perspective, although this fact was not immediately apparent to U.S. contractors because of the technical data shortcomings described above.

Elements of the first two categories affect a third set of activities associated with the selection and qualification of parts. In addition to the changes involved in adapting a design to U.S. requirements, European reliance on commercial parts and processes usually requires that Mil Spec and Mil Standard equivalents be identified or special qualification tests be held. In the Roland program, U.S. contractors expected to find U.S. Mil Spec/Mil Std. parts to substitute for 90 percent of the European parts, but initially, relying on extant U.S.-European parts conversion lists, they found closer to 60 percent. A subsequent search increased the count to 80 percent. "Near equivalent" parts[42] were found for an additional 6 percent; the remaining 14 percent were purchased from European vendors.[43]

Potentially the largest cost component of the technology transfer process is the effort necessary to accommodate differences in manufacturing practices. Design and manufacturing, material processing, and quality control methods are not standardized within Europe and often differ from those used in the United States (as noted in Section II). European manufacturing processes are generally more labor-intensive than American processes, often requiring worker skills that have almost disappeared as American industry has automated. One consequence is that U.S. production in the European manner would require more floorspace and single station machines than are available to Hughes Aircraft, the prime contractor. The probable design adaptation would involve a significant amount of preproduction effort by the transferee.

Although in theory a technology transfer program should allow the transferee to reduce its system test activities dramatically, there are several reasons why a transferee must ex-

[41]See also Lawrence (n.d.), p. 6. The license had no penalty provisions for late data deliveries and contractor and government sources differ about the practicality of using penalties in such a situation. Some U.S. contractor officials suggest that insistence on such provisions would have prevented the consummation of the license agreement while U.S. government officials insist on the need for such penalties.

[42]For example, capacitors with identical electrical properties that are different sizes and that possess slightly different finishes.

[43]Malone (1980), pp. 47, 69. For components that did not require very high reliability, a commercial item was used. Such parts were "upgraded" by a "burning-in" process at the factory, as well as by thermal cycling and vibration tests.

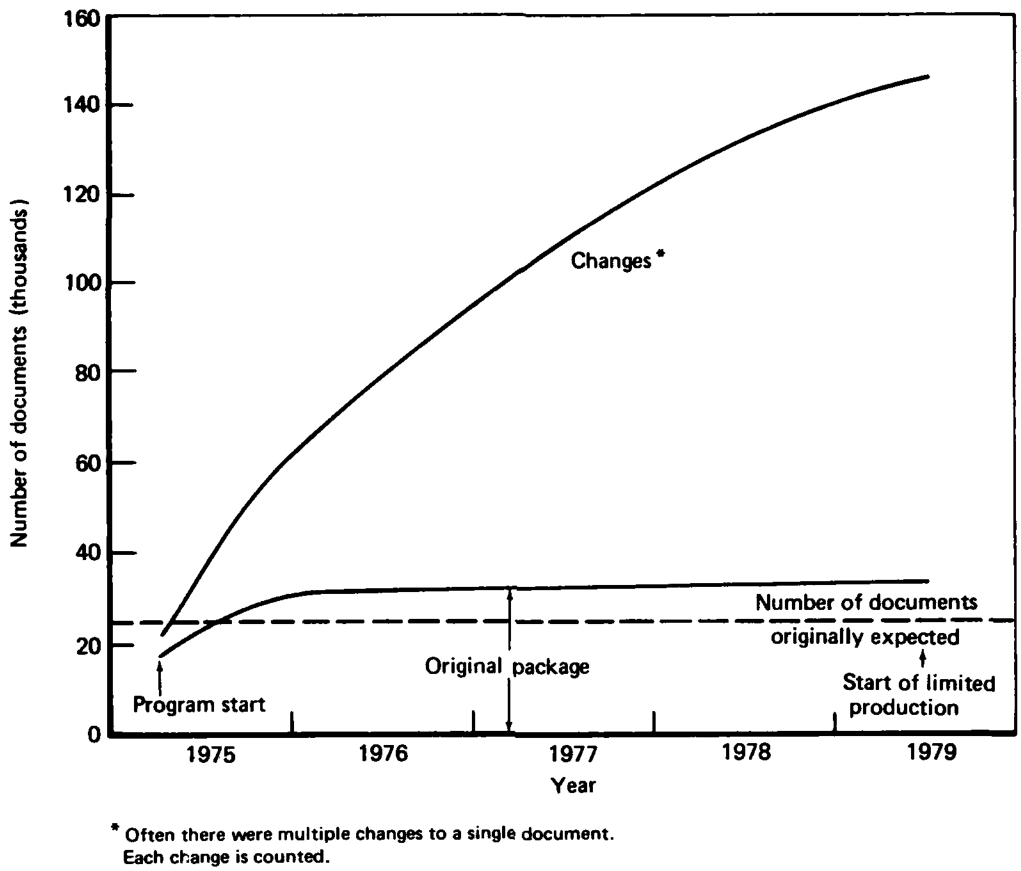

Fig. 12—Document receipt at Hughes Aircraft in the Roland program

pect a considerable amount of test activity. As our earlier discussion showed, European military services generally test their equipment to a less diverse set of conditions than does than the United States. This is due in part to different support concepts and to a narrower spectrum of operational and environmental factors with which European equipment must contend. Although the results of some of the performance testing done by the transferor nation can be used, the special operational and support requirements of the transferee can necessitate additional testing; design changes, parts replacements, and the need to qualify items produced by U.S. methods can require even more testing.[44]

Intended to be broadly representative of the sets of activities likely to constitute the major components of technology transfer cost, these activities can reduce the potential savings of such a program from the transferee's perspective. The difficulty and uncertainty of most of these activities, often exacerbated by the paucity of American experience with these types of arrangements, can also contribute to real program cost growth.

[44]In the Roland program, for example, the American missile propellant had slightly different burning characteristics—and thus slightly different performance attributes—than the original European propellant. The U.S. Army had to devise tests to assure that these differences did not alter basic missile system performance.

Roland Cost History.[45] The U.S. Army and its contractors overcame most of the problems and barriers described in the previous discussion; by all indications, the European Roland technology was successfully transferred and low-rate production did begin. In the initial stages of full-scale development,[46] Roland program cost estimates remained fairly stable. However, about two years into FSD, dramatic cost escalation occurred as program cost estimates were formally revised and the program was restructured.[47] For the next two years, cost escalation continued at an annual rate of about 16 percent, over and above inflation, a rate that substantially exceeded the average of all 1970s programs (see Fig. 13).

Not only do the magnitude and rate of Roland's cost growth stand out against other programs of its time, so do the contributing causes of that growth. Through March 1981, three years after the start of FSD, four-fifths of Roland cost growth was attributable to estimating errors (Table 12).[48] This proportion is more than twice as great as that of the average of contemporary programs (Fig. 14). However, cost growth due to post-DSARC II alterations in physical or functional characteristics of the system (the Engineering category in Table 12 and Fig. 13) was markedly less in Roland than in other programs. Although it is impossible to quantify the extent to which the multinational character of the Roland program is responsible for the abnormal size and distinctive distribution of this cost growth,[49] there is ample reason to suspect that it is a *major* reason for both.

Cost growth due to estimating errors[50] is, not unexpectedly, prominent in programs in which there is little early technical information about the design's physical and performance characteristics. Past U.S. attempts to adapt European technology fall into this category. U.S. unfamiliarity with the role of a technology recipient and the limited access to technical data allowed by European contractors before the contract award were the principal causes for the overly optimistic estimates in the Roland program. This, together with a subsequent direction from OSD to strive for maximum component interchangeability,[51] led to an incomplete appreciation of the magnitude of the task required to adapt the design to U.S. manufacturing methods.

Preparation of the missing IDL involved considerable unexpected effort (including some independent engineering analysis), as did the task of translating and converting European drawings to U.S. standards. IDL development also identified design, manufacturing, testing, and inspection specifications that were inadequate, missing, or not descriptive of shop floor practices. This additional effort (often involving independent engineering analysis) accounts for the cost growth in the SAR Overrun/underrun category, which is rarely significant in other programs.[52]

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[45]Data used in this subsection come from Roland Selected Acquisition Reports covering the period from December 1975 to March 1981.

[46]In the Roland case, FSD corresponds to the start of the technology transfer, fabrication, and test phase (TTF&T).

[47]This restructuring was due to difficulties encountered in the technology transfer process. At the time of this writing, proposals to cancel the program were under consideration.

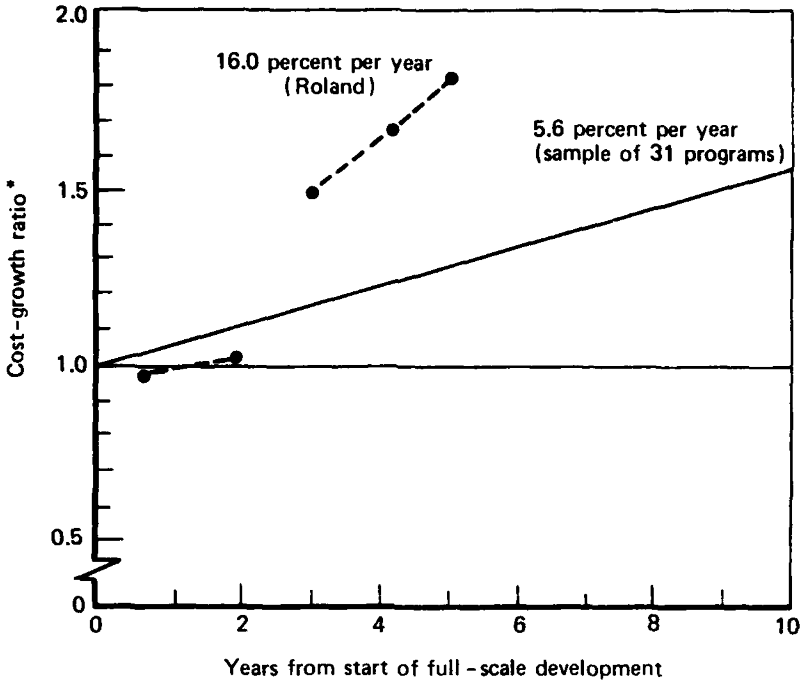
[48]Early estimates were overly optimistic in part because of European reluctance to release information about the design before program approval. The errors occurred in estimates of both the missile cost and the cost of the fire units.

[49]This stems in part from limitations of the SAR cost variance classification process itself.

[50]Defined as growth resulting from correction of estimating errors in the baseline cost projection or from refinements in the (physical) basis for the original estimate, contract renegotiations, availability of actual cost data, or a change in the slope of the assumed learning curve.

[51]See Malone (1980).

[52]This category includes cost variance subjectively attributed to the performance of the contractors. In practice, the Overrun/underrun category seems to be used only when a cost change cannot reasonably be assigned to one of the other categories.



*Ratio of current program cost estimate (various dates) to estimate made at start of full scale development.

NOTE: The data here have already been adjusted to eliminate the effects of inflation and variations in quantity. This figure does not, however, reflect Roland cost growth during the last two years, which is discussed in text accompanying Table 13 below.

SOURCE: Roland SARs, and Dews et al. (1979). Cost data in that report are also taken from Selected Acquisition Reports.

Fig. 13—Cost growth over time, Roland and other 1970s programs

One of the categories of cost growth in the Roland program that appears unusually small is Engineering. This is explained more by the size of the growth in the estimating error category than by the absence of cost growth due to changes in the physical and functional aspects of the missile and fire control system. There was some new development undertaken by U.S. contractors in response to several more stringent U.S. Army operational and support requirements[53] but the amount of this additional development and its contribution to overall program cost growth should not be overstated.

During 1980, the program was scaled back considerably. By early 1981, missile production quantities were reduced by over 80 percent, with similar reductions in numbers of fire units and vehicles. As of March 1981 the Reagan Administration had restored the program to its original size. Adjusting for inflation and quantity changes, estimated original total pro-

[53]These included development of a higher-powered radar to resist enemy ECM and a Field Maintenance Test Set (FMTS) to accommodate the greater autonomy of U.S. Army units.

Table 12

CONTRIBUTING CAUSES OF ROLAND COST GROWTH[a]

SAR Cost Variance Category	Contribution to Total Cost Growth (Percent)
Schedule	0
Engineering	4.1
Estimating	80.5
Support	(1.6)[b]
Overrun/underrun	12.9
Other	0
Quantity	4.1
TOTAL	100.0

[a]These data are derived from the March 1978 Selected Acquisition Reports. For an explanation of SAR cost variance categories, see *Department of Defense Instruction 700-3G, Guide for the Preparation and Review of Selected Acquisition Report (SAR) Cost and Economic Information.*

[b]Savings in the Support category offset a small fraction of the cost growth in other categories.

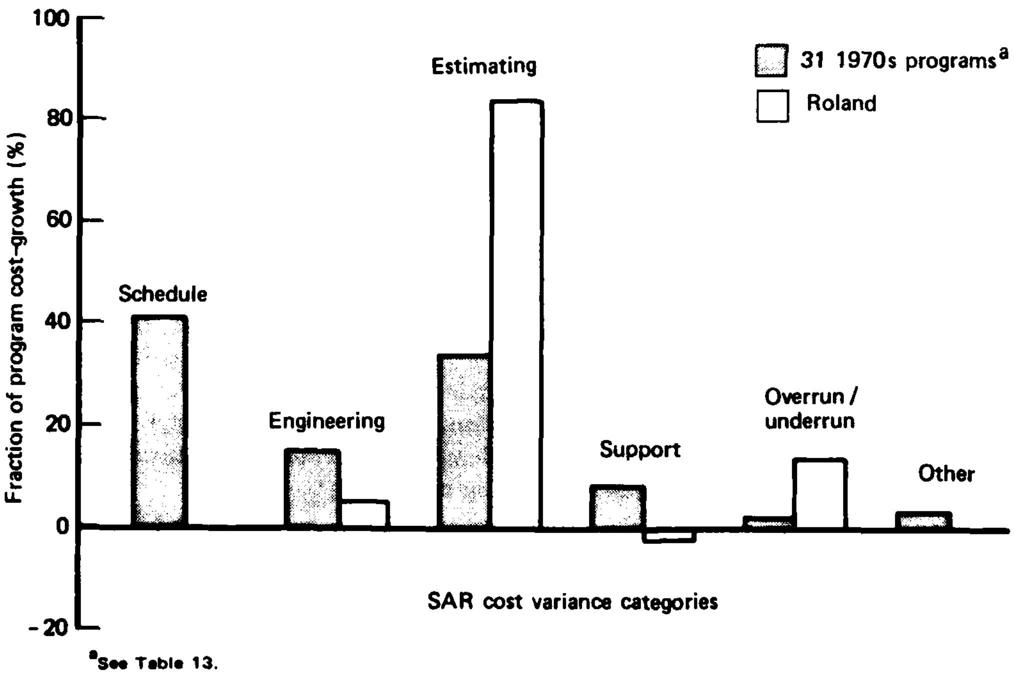


Fig. 14—Distribution of program growth, Roland and other 1970s programs

gram cost growth has exceeded 200 percent. This cost growth is considerably greater than most other U.S. weapon system programs of the 1970s (see Table 13).

Past experience in such programs as Roland, although very limited, underscores the fact that programmatic risks are not necessarily reduced by producing a European design in lieu of developing a new system. As the most prominent and costly example of a weapon system transfer from Europe, the Roland program has been subject to intense oversight by OSD, the Congress, and the U.S. Army. During its first 21 months, the program experienced at least six different TTF&T program concepts, each having different projected costs and lengths ranging from 54 to 74 months.[54] In 21 months early in its life, it underwent seven special reviews, much like those conducted by Army or Defense System Acquisition Review Councils (ASARCs/DSARCs), far more than would typically occur in a national program.[55]

Table 13

ROLAND COST GROWTH COMPARED WITH THAT OF OTHER PROGRAMS

Program	Cost Growth Ratio[a]
Roland	>2.0
31 DoD programs of the 1970s[b]	1.20
10 Army programs of the 1970s	1.18

SOURCE: Roland SARs, and Dews et al. (1979).

[a]Ratio of "current program" cost estimate (31 March 1981 for Roland; 31 March 1978 for the others) to estimate made at the start of full-scale development. Cost growth due to inflation and production quantity changes is excluded (estimate based on original production quantities and adjusted to program base year dollars).

[b]*Army:* Patriot, Hellfire, Roland, UH-60, AH-64, IFV, XM-1, Copperhead, DIVAD, M-198 Howitzer; *Navy:* F-18, LAMPS III, Aegis, CAPTOR, Harpoon, AIM-9L, Tomahawk, 5-in. guided projectile, 8-in. guided projectile, SURTASS, TACTAS, Condor; *Air Force:* A-10, B-1, F-15, F-16, E-3A AWACS, DSCS III, ALCM/GLCM.

Devoting more time to making early estimates of cost and to preparing for production might yield some dividends. Another alternative is to make more funding available to potential licensees (before the contract award). This might reduce both European reluctance to share information about a design and the uncertainty of early U.S. contractor estimates. In addition, there is a need to develop a fuller understanding of the implications of U.S. and European differences in design and manufacturing practices.

Duplicating Fabrication and Assembly Responsibilities

When production tasks are distributed to individual program participants, the longer production runs characteristic of multinational programs will generally yield economies of

[54]Lawrence (n.d.), p. 8.
[55]Malone (1980), p. 64.

scale (and consequent lower average unit prices). However, if production responsibilities are shared by two or more participants, potential benefits of scale are lost and the risk of inefficiencies is increased. Such duplication is not common in all-European programs. In the Alpha Jet program, for instance, only final assembly is performed in more than one nation. By contrast, U.S. preference for a near-total indigenous production base for every system acquired, to eliminate dependency on foreign sources of supply, means that some duplication of effort is an automatic feature of every U.S. multinational program.

Approach. To examine the effects of duplicating fabrication and assembly responsibilities, we examined two American programs that featured multiple production and assembly lines: (1) the B-52, produced by Boeing, first in Seattle and then Seattle and Wichita simultaneously; and (2) the F-100, produced by North American Aviation, first in Los Angeles and then in Los Angeles and Columbus, Ohio, at the same time. For each program we estimated the incremental effects of the second facility on each of the major components of airframe production cost—engineering, tooling, manufacturing, materials, and indirect cost. These components are not equal contributors to overall airframe production cost, of course (see Fig. 15). Noting the relative magnitude of each cost category is therefore important in understanding the probable overall effect of duplication.[56]

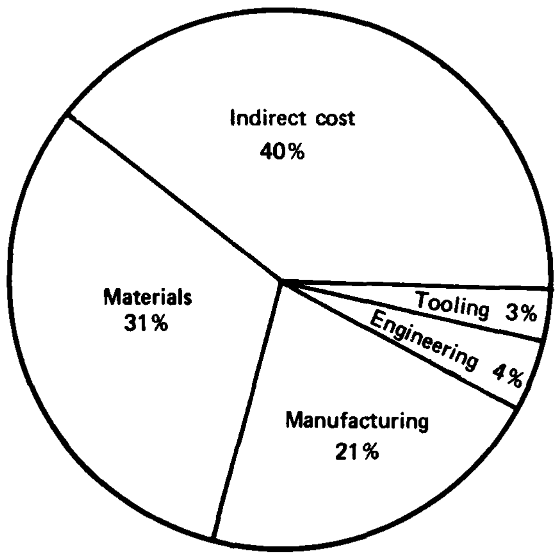


Fig. 15—Typical distribution of military airframe production cost*

* Percentages shown are mean cumulative average values at the 100th unit for three military aircraft programs (2 fighter, 1 cargo)

[56]For ease of discussion, we have treated each cost element as an independent, self-contained entity. In reality, however, each is affected by the others, as well as by various external factors (production rates, productivity, etc.). An increase in effort in one category can reduce the incremental effort in another category, for instance.

Engineering. Engineering activities during the production phase include redesign, reliability and maintainability improvement, and technical coordination of design and manufacturing work. The size of this effort is partly fixed, reflecting the necessity of maintaining a constant engineering capability, although it also varies with production rate and quantity.

We estimated the incremental effect of production at a second facility by comparing the actual number of engineering hours accumulated at that facility with the estimated number of hours that would have been accumulated had the same quantity been produced instead at the original facility. (For purposes of this comparison, possible impediments to the extra production at the first facility were ignored.)[57] The results for the two cases were ambiguous (see Table 14). In the case of the B-52, we estimated that the engineering hours at the second facility (Wichita) exceeded by 10 percent the amount that production at the first facility (Seattle) would have required. That result is consistent with learning-curve theory. However, in the F-100 case, production at a second facility required only about half as many hours as is estimated to have been required in the postulated single facility arrangement, because the second facility had a much smaller fixed engineering staff.

Table 14

ESTIMATED EFFECT OF SECOND FACILITY ON TOTAL PROGRAM PRODUCTION ENGINEERING EFFORT

Aircraft	Number Produced at Second Facility	Actual Engineering Hours at Second Facility (000s)	Estimate of Hours Required at First Facility to Produce Same Quantity (000s)	Estimated Incremental Effect of Second Facility (Percent)
B-52	172	2666	2400	+10
F-100	359	225	470	−48

Transferring production to a different company might be more of a problem, depending on the completeness of the technical data package, facilities and equipment compatibility, and worker skill levels. In general, experience in single nation programs probably understates the effect on engineering effort of coproduction in an inter-firm and international context, where the liaison and engineering support demands are probably far greater.[58] In any case, this category usually represents just a small fraction of overall airframe production cost.

Tooling. The second cost category, tooling, includes the labor necessary to outfit an airframe production facility with article-specific equipment—jigs, fixtures, dies, work platforms, etc. Not included are general purpose tools, such as drills, presses, and milling machines, which are included, usually as "production supplies and services," in the indirect cost account. Like engineering costs, these costs are a very small proportion of the total.

[57]Such impediments might include a lack of floorspace or a shortage of qualified production workers.

[58]For a detailed description of the effort required in the F-104J program and earlier Lockheed-Japan collaborations, see Hall and Johnson (1967), pp. 107-113.

In general there are two ways to increase the production rate of a program. The first uses the existing facility more intensively, by adding either labor inputs (e.g., multiple shifts) or capital inputs (e.g., tooling improvements). A second way, and one most relevant to coproduction, is to begin producing at a second facility. The second course is typically more expensive than either variant of the first.

In the F-100 and B-52 programs, the duplicate tooling efforts required for production at the second facilities were substantial. For example, the second F-100 facility (at Columbus) required almost as many nonrecurring tooling hours (2.7 million vs. 2.8 million) as did the first facility (at Los Angeles), even though its maximum production rate was to be 40 percent less. Comparing the actual tooling effort at the second facility with an estimate of what a longer production run at the first facility would have required showed that the incremental effect of duplicating production facilities was substantial: Production at two facilities involved over four times as many tooling hours as production at a single facility option is estimated to have required (344 percent more in the case of the B-52, 388 percent more in the case of the F-100).

Manufacturing. The third category, manufacturing, covers most of the activities traditionally thought of as constituting "production"—e.g., fabrication and assembly. Depending on the number of units produced, these activities constitute about one-fifth to one-third of total airframe production cost. An important cost-quantity relationship in the case of manufacturing depends on the analytical assumption that for a constant production rate, program workforce is reduced as learning occurs (or for a given labor force, production rate increases). This is more likely to be true in the United States, where workers are often transferred between projects or laid off, than in Europe, where workforce policies are generally less flexible.

To illustrate the cost-quantity relationship and the effect on manufacturing hours of production at a second facility, Fig. 16 presents a representative, although hypothetical, airframe manufacturing learning curve. The vertical axis, which uses a logarithmic scale, measures manufacturing man-hours per pound; the horizontal axis, which is also logarithmic, measures production quantity. The curve shows the learning that occurs during a production run of 100 units.

The relevant policy question, again hypothetical, is whether to produce an additional 100 units at the original or at a second facility. In Fig. 17, the first alternative is illustrated by the dashed line extending from the first facility's curve.[59] The second alternative is illustrated by the lower solid line. This curve starts lower because there is evidence that some learning can be transferred from the original facility to the second facility.[60] It is drawn parallel to the first curve only as an illustration because the rate of learning (the slope of the curve) at a second facility may be different from that at the first.

To illustrate the comparison of the two alternatives in Fig. 18 we have moved the second facility curve to juxtapose it with the extension of the first facility curve. Note that the logarithmic scale changes the appearance of the slope, although the slope itself remains the same. The shaded area between the curves is the additional effort required by the second

[59]Because of the logarithmic scale, the lengths of the original curve and the dashed extension are different, although each represents production of the same quantity.

[60]The F-104J and Japanese T-33A programs are good examples. See Hall and Johnson (1967), pp. 150-156.

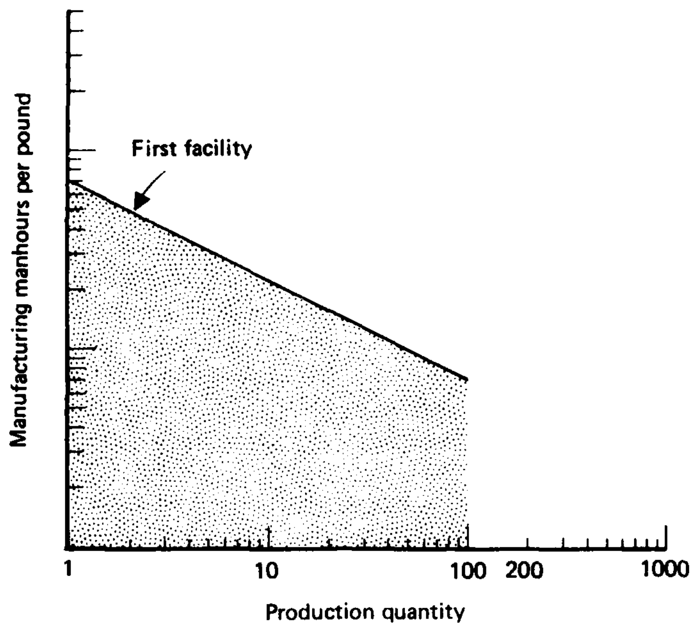


Fig. 16—Manufacturing effort to fabricate
100 units at one facility

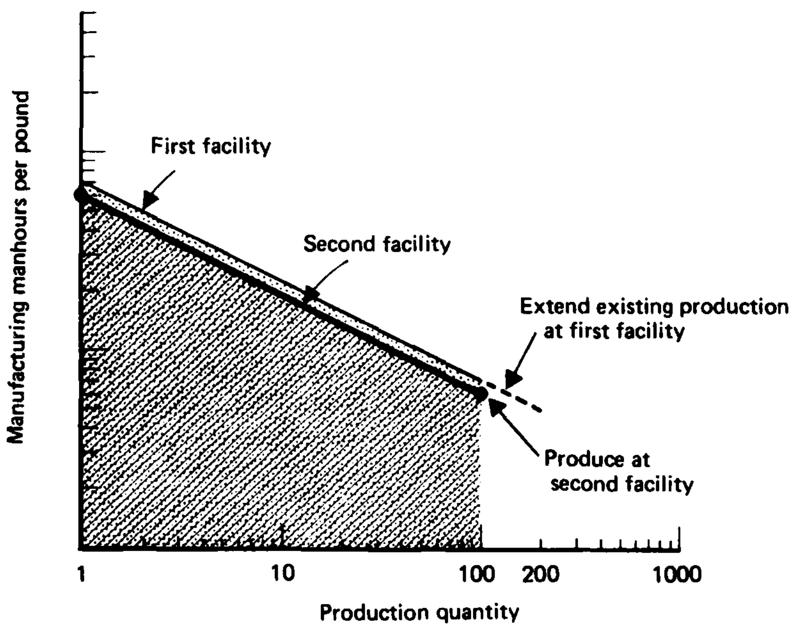


Fig. 17—Options to manufacture 100 additional units

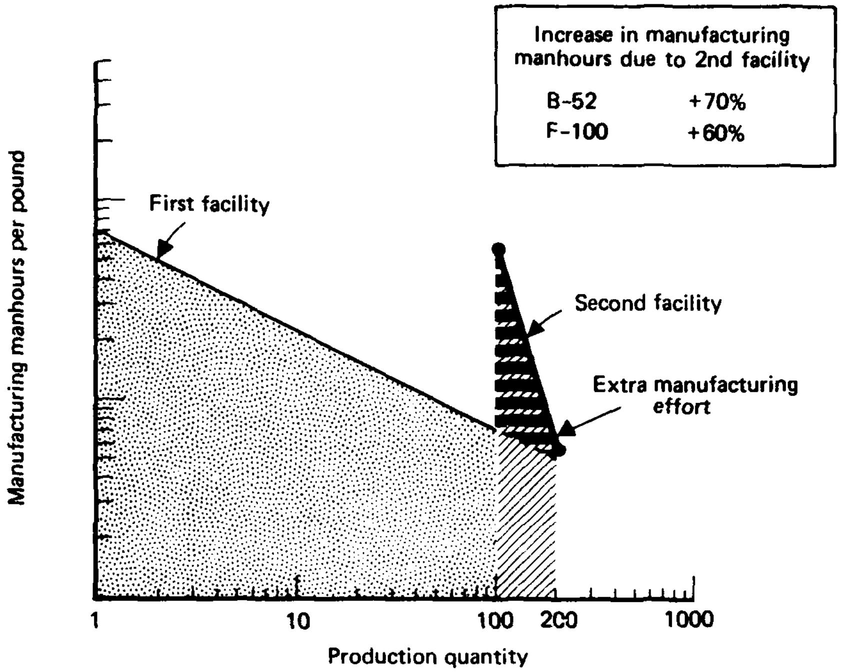


Fig. 18—Increase in manufacturing effort to produce at a second facility

facility—beyond what would be required at the original facility—to produce the second 100 units.

Although the example is hypothetical, the actual effect of production at the second facilities in the F-100 and B-52 programs was measured. The effect was significant: Producing at two facilities instead of extending the original production run caused an increase of 60 to 70 percent in manufacturing man-hours.

Materials. Materials typically account for almost a third of airframe production cost. This includes both manufacturing materials—either raw or semifabricated—and purchased equipment (pumps, batteries, instruments, etc.). Like manufacturing labor, materials cost is affected by learning, which reduces scrappage, waste, etc. In addition, in large production runs the contractor can make volume purchases at reduced prices. There is therefore a cost-quantity effect for materials, although it is much less pronounced than for labor.[61]

In theory, duplicating production and assembly facilities need not affect materials cost.

[61]An 85 percent learning curve slope is typically followed for materials in the United States, although a trend toward smaller production lot quantity and near-capacity operations by materials suppliers may result in shallower slopes in the future. By comparison, a 75 percent slope is often mentioned as typical of U.S. manufacturing efforts.

Experience in the F-100 and B-52 programs shows that cost-quantity benefits can be realized in spite of the duplication if three conditions are satisfied: materials purchasing is centralized (or at least coordinated), purchases are made on a least-cost basis, and production rates are efficient.

Realistically, some of these conditions will be difficult to achieve in most multinational programs. In the F-16 program, for example, materials purchasing is generally centralized or coordinated, but many purchases are geographically dictated by the governing Memorandum of Understanding.[62]

Indirect Cost. The largest portion of the production cost of an airframe, usually just under half of the total, is indirect cost. This includes indirect labor, employee benefits, taxes, administration, and many other overhead activities. Each plant has its own overhead rates,[63] which are a function of its business base and internal organization. Figure 19 displays the normal relationship between overhead rate and business base. As business volume increases, overhead rate decreases; however, the rate of change varies greatly from company to company. Therefore, transferring production to a facility with a lower overhead rate can actually reduce a program's total indirect cost when the overhead cost reduction at the second facility exceeds the forgone decrease in cost at the first facility. That is what occurred in both the F-100 and B-52 programs.

Summary. This subsection has dealt with the effects of duplicating production responsibilities. Experience in the B-52 and F-100 programs shows that the levels of effort in the two smallest cost categories—engineering and tooling—will probably increase. However, increases in man-hours do not necessarily imply greater costs; if wage rates at the second facility are lower than those at the original facility, they could offset the additional man-hours.[64] Manufacturing costs will usually be higher because of the loss of some economies of scale. The effect on the two largest cost categories—materials and indirect cost—is uncertain, depending on the circumstances of each program. Careful structuring of program policies—coordination of materials purchasing, for instance—can actually produce cost savings, which would have a marked effect on total production cost. This is especially significant for equipment whose production is more materials-intensive—e.g., turbine engines. The effects of duplication in those programs could be less severe.

Currency Fluctuations

In recent years, most currency exchange rates have fluctuated widely.[65] Figure 20 illustrates the movement of various Western European currencies relative to the U.S. dollar. The U.S. dollar is generally in a stronger position relative to the Italian lira and the British pound today and in a weaker position relative to the other currencies than it was at the beginning of the 1970s. In a number of programs currency fluctuations increased costs for some program participants. On the MRCA program German parts became substantially more

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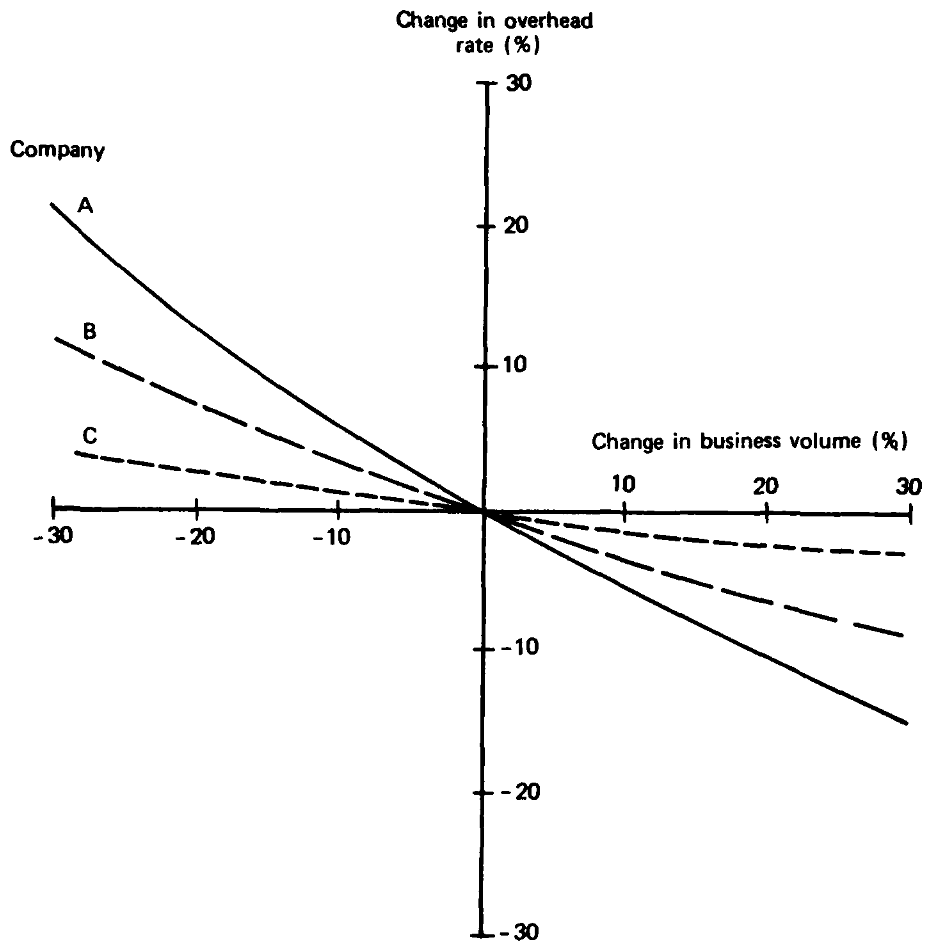
[62]See Section IV for more details.

[63]Overhead rate is defined as total overhead cost divided by total direct labor cost; material cost does not enter the calculation.

[64]This occurred in the F-104J program, where lower wage rates lowered production costs. See Hall and Johnson (1967), pp. 150-156.

[65]For information on the causes of currency fluctuations and changes in international money markets, see Robert Z. Aliber, *The International Money Game*, 3rd Ed., Basic Books, New York, 1979; Herbert G. Grubel, *International Economics*, Richard D. Irwin, Inc., Homewood, Illinois, 1977; and Richard E. Caves and Ronald W. Jones, *World Trade and Payments: An Introduction*, 2nd Ed., Little, Brown and Co., Boston, 1977.



SOURCE: Data furnished to Rand by aerospace contractors.

Fig. 19—Sensitivity of overhead rate to changes in business volume for three U.S. aerospace contractors

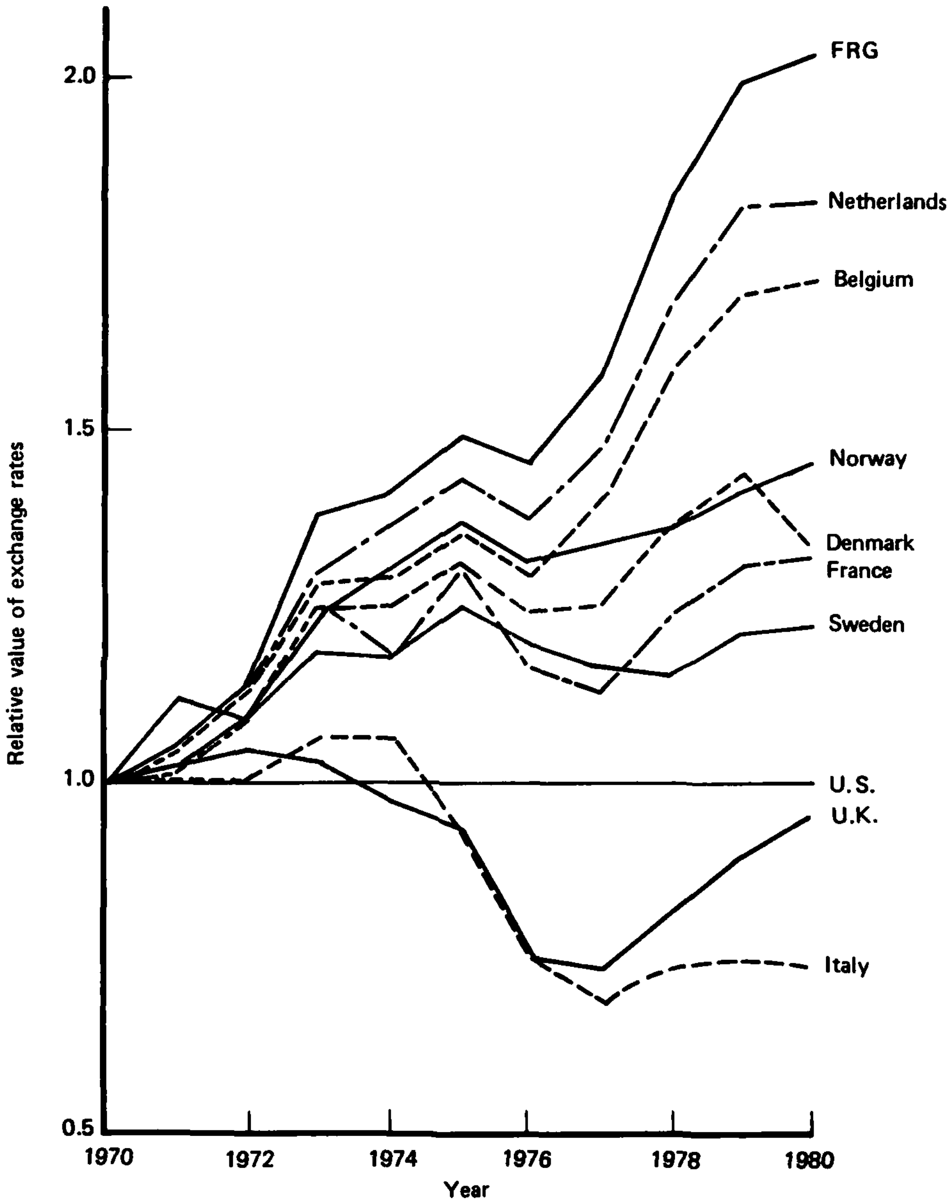


Fig. 20—European currency fluctuations relative to the U.S. dollar

expensive to the British as a result of currency fluctuations. On the MRCA, all prices are quoted in German marks. Because it has been the strongest currency, and exchange rates float, this has increased costs for the other two nations on the program.

On the two most recent coproduction programs involving the United States, exchange rate fluctuations have increased the cost of the program to the United States. The F-16 MOU specifies that financial procedures are to be based on the principle that no U.S. or European contractor "shall realize financial benefit nor incur financial loss by reason of fluctuations in the official rate of currency exchange."[66] However, there is no similar agreement protecting the interests of the governments, and exchange rate fluctuations are expected to add $40 million to U.S. program cost. On the Roland program, Hughes pays royalties to Euromissile in German marks at the going rate. Since exchange rates are not fixed in the MOU, the U.S. Army must bear the cost of the increased value of the mark. The increased costs are passed on to the Army through their cost reimbursement contracts.

Such fluctuations in program cost with fluctuating exchange rates are not inevitable but are a result of the common practice of stating prices in a single currency (typically the seller's) and not specifying an exchange rate. There are methods of reducing currency risk, such as specifying that program participants are to be paid in a particular combination of currencies (typically called a basket).[67] Such approaches have been successfully used to reduce the risk of increased price due to changes in exchange rates. For example, on the Raytheon Seasparrow project, currency losses and gains are evenly divided among program participants.

In January of 1980, an Assistant Secretary of Defense (Comptroller) Memorandum set up new guidelines for currency arrangements in international agreements. According to these guidelines, the preferred arrangement is to have all prices stated and payments made in U.S. dollars. This would eliminate all influence of exchange rate fluctuations for the United States. If this option is not available, the next preferred option is to have prices stated and payments made in a basket of currencies. Both of these options are to be preferred over payment in a single foreign currency.[68] This appears to be a sound policy for reducing currency risk. Recently, most major international banks have begun offering long-term, fixed price contracts for major currencies. They now routinely quote firm exchange rates for as much as five years into the future.[69] In some cases, this could be a desirable way of eliminating all currency risk, even if prices are quoted in a foreign currency. However, the policy memorandum forbids any use of forward contracts for currencies. It may be possible to reduce some currency risks by relaxing this prohibition and allowing limited use of such contracts.

ACQUISITION MANAGEMENT

Certain features of multinational programs will probably make it more difficult to adhere to the detailed set of government regulations and underlying principles that guide the management of American major weapon system acquisition programs. Office of Management

[66] Section C.15.a.

[67] For more details on the mechanics, see R. Adams and R. Perlman, "Long-Term Contracts in a Flating World," *Euromoney*, December 1973, pp. 49-53.

[68] Assistant Secretary of Defense (Comptroller) Memorandum, "Department of Treasury Policy for Financial Transactions with Foreign Nations and International Organizations," 31 January 1980.

[69] "A Forward Market's Long Reach," *Business Week*, Novemb~~ 23, 1981, p. 103.

and Budget (OMB) Circular A-109 and Department of Defense Directives 5000.1 and 5000.2 govern the current acquisition process. The key features are a set of OSD program reviews at specific points in a system's life cycle (intended mainly to assure that important goals of each development phase have been achieved before initiation of the next phase) and special emphasis on the use of competition. Since release of OMB Circular A-109, there has also been increased emphasis on formally establishing a need for a program (in a MENS—Mission Element Needs Statement) before it begins and on exploring a variety of technical approaches early in development.[70]

Recent changes in the acquisition system initiated by Deputy Secretary of Defense Frank Carlucci include reducing the number of program reviews, giving more management responsibility to the services, and putting more emphasis on planning in the Planning, Programming, and Budgeting System (PPBS). Experience suggests that satisfying these general objectives may be difficult in multinational programs.

Program Review and Control

An acquisition program is divided into several distinct phases, with major reviews at the transition points between phases (called milestones; see Fig. 21).[71] When a program comes to the end of a phase, the Defense Systems Acquisition Review Council (DSARC), a group of high-level OSD officials, conducts an extensive program evaluation. On the basis of a DSARC recommendation, the Secretary of Defense decides whether a program should proceed to the next phase.

It is not unusual for critical decisions—whether and when to proceed to the next phase—to be made outside the usual DSARC process in multinational programs. In the F-16 program,[72] for example:

- The decision to enter full-scale development was made 11 months before the program passed Milestone II.
- The decision to enter production was made 30 months before the program passed Milestone III.

The DSARC review process at Milestones II and III was merely a formality.

There is no evidence that the aforementioned decisions were ill-advised, but the pattern raises serious questions about the management of future programs. Early decisions that do not have the full benefit of information generated during the development phases increase the technical risk in a program. Although the pressure for early commitments will often be great in multinational programs, it should not be allowed to undermine the orderly acquisition management process.

Use of Competition

Two factors combine to lessen the potential amount of competition in multinational programs that feature foreign production of U.S. designs. The first is the effect of offset agree-

[70]OMB Circular A-109, "Major System Acquisitions," 5 April 1976; DoD Directive 5000.1,"Major System Acquisitions," 19 March 1980; DoD Instruction 5000.2, "Major System Acquisition Procedures," 19 March 1980. For a discussion of the evolution of defense acquisition policy, see *Smith and Friedmann (1980)*, pp. 2-6.

[71]DSARC procedures are being revised by the Reagan Administration at the time of this writing.

[72]Section IV discusses the F-16 program in far more detail.

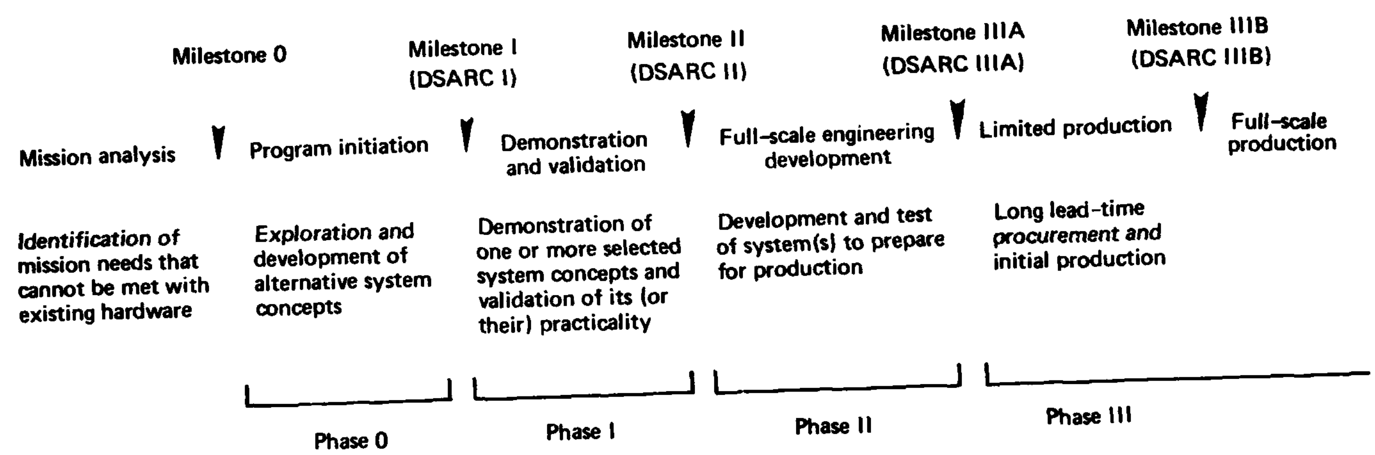


Fig. 21—Acquisition program phases and milestones

ments, which stipulate placement of work in specific geographic regions (usually specific nations). Such provisions generally inhibit the selection of the least-cost supplier. Moreover, once limited to a particular European nation, U.S. contractors typically find single bidders for available contracts, and these are often preselected by the government.[73] Over 80 percent of the European F-16 contracts were negotiated on a sole source basis after the European government had specified a source.

Family of Weapons Concept

One of the officially endorsed means to achieve rationalization, standardization, and interoperability is the Family of Weapons (FOW) concept: "Under this concept, participating NATO nations would reach early agreement on the responsibility for developing complementary weapon systems within a mission area,"[74] Although it is too early to know how the FOW concept will work in practice, there is a danger that early specification of hardware development responsibilities will conflict with A-109's intent that competition among technical alternatives to satisfy generic mission needs be maintained for as long as possible.

U.S. and European collaboration on a MENS prior to establishing a family of weapons and the associated program packages is one way to minimize this conflict. NATO's Council of Armaments Directors (CNAD) is currently setting up the Periodic Armaments Planning System (PAPS), a system of phases and milestones similar in many ways to OSD's DSARC system. PAPS would provide for international discussion and coordination of mission needs among NATO members that may help to resolve this conflict.[75] An alternative approach would be to conduct Phase 0 studies and FOW discussions in parallel, deferring until Milestone I or beyond the required date for a final MENS.[76] However, achieving the twin objectives of competitive exploration of technical solutions and multinational division of primary program responsibilities probably requires extensive coordination of these processes and ultimately some relief from the inevitable pressure for early commitments from prospective collaborators.

Program Stability

Observers have noted with increasing frequency the negative effects of program turbulence or instability.[77] A substantial fraction of the cost growth recently experienced in U.S. defense programs is caused by production schedule changes;[78] additional growth is caused by changes in program scope. Although some of this change originates within the program, much of it is caused by outside events and actions, such as production run stretchouts in response to externally caused budget difficulties. Numerous proposals to increase program stability, including multi-year appropriations, are now under discussion.

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[73]See also "Procurement Policy Causing Struggles," *Aviation Week & Space Technology*, 26 November 1979, p. 39; OUSDR&E, *Report of the Defense Science Board Study Group on NATO Family of Weapons*, Washington, D.C., 30 January 1979, p. 7.

[74]DoD Directive 2010.6, "Standardization and Interoperability of Weapon Systems and Equipment Within the North Atlantic Treaty Organization," 5 March 1980, Sec. D.4.c.

[75]For more on the details of the PAPS, see the *Joint Logistics Commanders Guide for the Management of Multinational Programs*, Defense Systems Management College, Fort Belvoir, Virginia, July 1981, pp. 3-5 to 3-14.

[76]See Smith and Friedmann (1980), pp. 38-41, for the original rationale for this suggested change in MENS policy.

[77]*Report of the Defense Science Board 1979 Summer Study on Reducing the Unit Cost of Equipment*, May 1980, pp. 7-8, 89-102; Dews et al. (1979), pp. 71-76.

[78]Dews et al. (1979), p. 72.

Although recent experience is mixed, multinational participation in a production program often leads t , greater stability. There has been no change in production rates in the F-16 program, aside from the vagaries of orders and cancellations from "third countries." Most program participants attribute this rare occurrence to the multinational nature of the program.[79] In other multinational programs, where the amount of direct European participation in U.S. production is far less (e.g., Roland), there has been a great deal of schedule turbulence. In general, collaboration probably has the beneficial effect of increasing program stability, with the associated cost of some reduced U.S. flexibility.

THIRD-COUNTRY TRANSFERS

Some program management issues stem from the effect of coproduction arrangements on the interests of potential European collaborators. For example, one of the more vexatious problems posed by multinational coproduction arrangements is establishing a third-country transfer policy acceptable to all parties. When technology flows from Europe to the United States, the issue is the fairly direct one of dividing the world market into exclusive sales territories, as in the case of Roland.

A far more difficult situation exists when the technology flows from the United States to Europe. The difficulty stems from two facts. First, the U.S. government must approve all transfers of equipment produced abroad under license,[80] just as it must approve retransfers of exported U.S. defense equipment (even if the item is incorporated in a larger system of foreign design).[81] Permission has been denied in both types of cases (e.g., Italy's request to sell F-104 fighter aircraft to Ecuador and Bangladesh and G.222 transport aircraft, which use General Electric engines, to Libya).[82]

The second fact is that European defense industries depend heavily on export sales, although not for the reason many believe: By the most common economic indicators, major European nations are still much less dependent on arms exports than the United States (although their dependency by those measures is growing rapidly; see Table 15), but the very small domestic requirements probably mean that, without exports, production runs would be uneconomical. To appreciate this, one need only compare the cost effects of a total loss of export sales in an American and a European program. For example, how would the loss of the approximately 350 foreign sales of the Mirage III have affected the cost of the approximately 200 Mirage IIIs in the French Air Force? And how would the loss of the 1100 or so exported F-4s have affected the cost of the approximate 3000 F-4s in the American inventory? Assuming average unit cost pricing, and 85 percent cumulative average learning curves in both cases, the average unit cost to the buyer of the domestic aircraft would be over 25 percent higher in the case of the Mirage, but less than 10 percent higher for the F-4.[83]

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[79]Various officials of the AV-8B program, including the program manager, have stated that they expect the same phenomenon. See David R. Griffiths, "U.S., U.K., Agree on AV-8B Program," *Aviation Week & Space Technology*, 10 August 1981, p. 63; "Long-Awaited British Buy Saves Harrier Program from the Whimsy of Politics," *Defense Week*, 29 June 1981, p. 7.

[80]22 CFR 124.10(m); see also 22 U.S.C. Sec. 2753 and DoD 5105.38-M, Part III, Ch. A, Sec. 1.

[81]See, e.g., 22 CFR 123.10.

[82]A few instances of unauthorized transfers have occurred: Libyan F-5s to Turkey and Israeli-built Mysteres with U.S. engines to Honduras, for example. However, several important transfers were approved during this period, too.

It is too early at this writing to project Reagan Administration changes in policy and procedure. There have been reports, based largely on language in the 1980 Republican Party platform, that an easing of arms transfer restrictions can be expected. See, for example, *Defense & Foreign Affairs Daily*, 31 July 1980, p. 2.

[83]It has been reported that Dassault "must export three Mirage fighters for every one sold to the French Air Force." U.S. Senate, Committee on Foreign Relations, *Prospects for Multilateral Arms Export Restraint*, Staff Report, 1979, p. 3.

Table 15

SELECTED ECONOMIC INDICATORS OF ARMS EXPORT DEPENDENCY

Country	Arms Exports as Percent of Total Exports 1967-1976	Arms Exports as Percent of Total Exports 1976	Arms Exports as Percent of GNP 1967-1976	Arms Exports as Percent of GNP 1976	Per Capita Arms Exports 1967	Per Capita Arms Exports 1976
United States	6.28	4.50	0.32	0.31	$17.71	$22.86
France	1.54	1.50	0.18	0.23	2.74	15.06
United Kingdom	1.23	1.40	0.19	0.26	2.81	10.80
Italy	0.51	0.75	0.08	0.15	0.66	4.68
FRG	0.41	0.60	0.07	0.14	1.55	10.02

The result of this combination of a perceived restrictive U.S. policy on arms exports and a substantial European dependence on such sales is a reluctance by some European nations to collaborate with the United States.[84] The fear that partnership with the United States may result in foreclosure of certain desired foreign sales is probably well founded; however, the assumption that such an arrangement will necessarily mean a net loss in total sales by the European nation is probably not. Even if the United States does prohibit third-country transfers to certain nations, under certain types of coproduction arrangements it could also make certain new markets available to its collaborators, and these additional markets are probably much larger than those embargoed.

This proposition can be demonstrated by analysis of the composition of one important world market: fixed-wing tactical combat aircraft and jet trainers.[85] The United States dramatically dominates this market.[86] The number of American aircraft in foreign inventories exceeds that of the next most successful exporters, France and Great Britain, by factors of about five and eight respectively (see Fig. 22). Western Europe enjoys few *exclusive* markets for tactical fighters and jet trainers; the U.S. exclusive world markets are forty times

[84]For examples of official U.S. Government recognition of this situation, see the remarks of Matthew Nimetz, Under Secretary of State for Security Assistance, Science and Technology, to the American Defense Preparedness Association, reported in *Defense & Foreign Affairs Daily*, Vol. IX, No. 142, 24 July 1980; U.S. House of Representatives Committee on International Relations, *Issues Concerning the Transfer of United States Defense Manufacturing Technology*, 30 June 1977, p. 23.

[85]That the proposition holds for other markets is not clear. Western Europe's share of the world military helicopter market is larger than its share of the world's military fixed-wing aircraft market. However, the helicopter inventories of the U.S. armed services are over three times larger than those of France, West Germany, Great Britain, and Italy combined. See "The World's Military Helicopter Fleet," *Interavia*, July 1980.

[86]There is a great deal of uncertainty in any analysis of the arms trade. See Edward A. Kolodziej, "Measuring French Arms Transfers," *Journal of Conflict Resolution*, Vol. 23, No. 2, June 1979, pp. 195-227. In this case, necessary conventions were designed to be conservative in terms of the hypothesis being advanced. For instance, the focus is on number of aircraft instead of the dollar value of systems transferred, which is impossible to ascertain. This focus also avoids analytic problems of distinguishing sales from loans and gifts. Trends in exports by the Soviets and non-European nations (e.g., Israel, Brazil) are largely unmeasured. European collaborative programs are dealt with in a simple fashion: For most purposes nations are credited with a fraction of ies to non-partner nations that equals their proportional production shares. Finally, aircraft produced under license are credited to the licensor, not the licensee, but systems of European origin are treated as European no matter the size of their content of American subsystems and components. These last two conventions probably counterbalance each other.

The primary source for data on fighter and trainer aircraft was *The Military Balance, 1979-1980*, The International Institute of Strategic Studies, London, 1979. Totals for the Alpha Jet, Tornado, and Jaguar programs were updated with information from "Military Aircraft Census," *Flight International*, 6 September 1980.

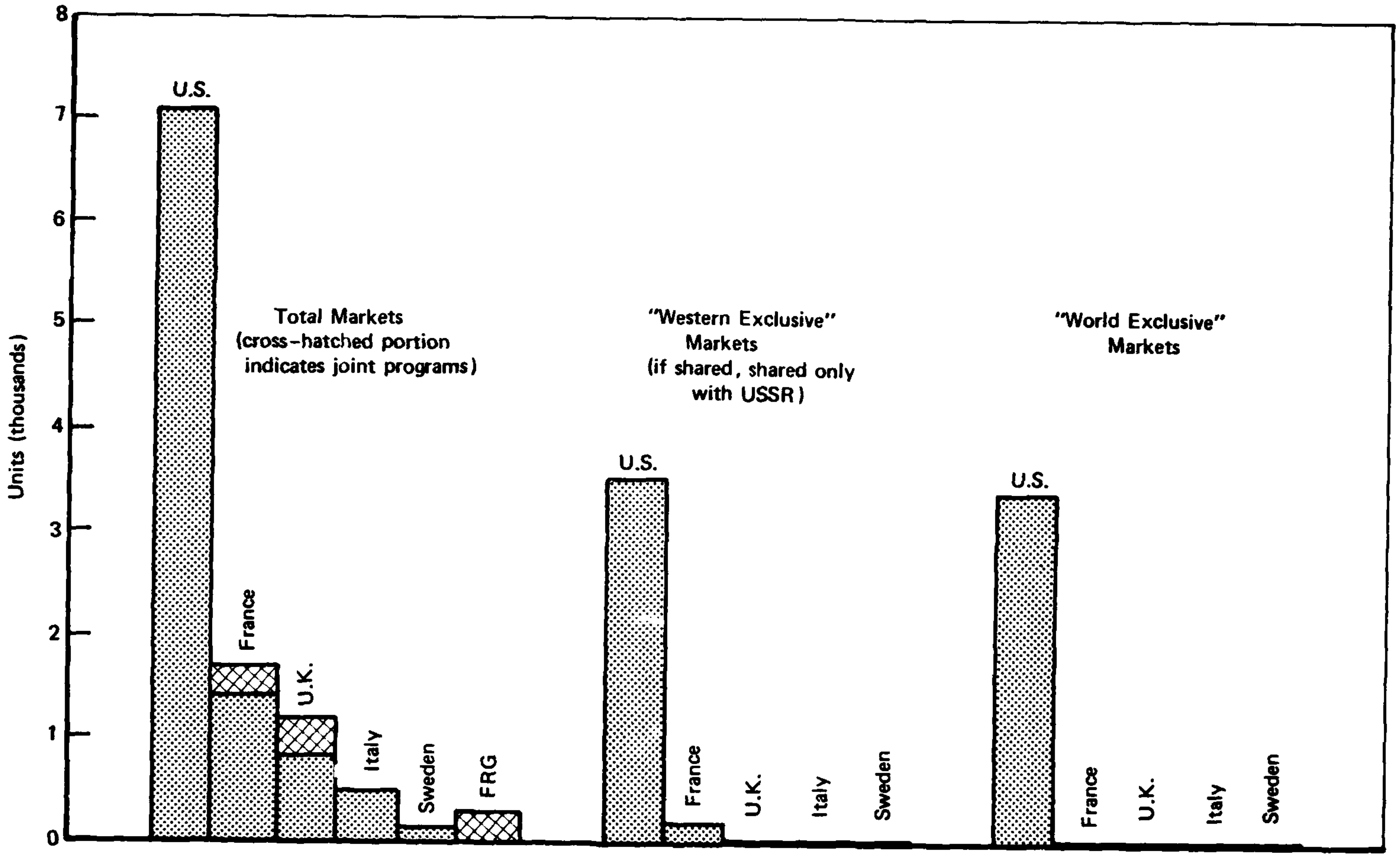

Fig. 22—Combat aircraft and jet trainers in foreign inventories
(by designer-nation)

larger than those of all of Western Europe combined.[87] Figure 22 includes aircraft in inventories and on order in 1979; eliminating orders from the calculations changes the proportions only slightly, suggesting that major alterations to this market disparity are not likely to occur in the near future. An exception is France, which, along with West Germany, will benefit from sales of the Alpha Jet to third-world countries.[88]

The U.S. inventories of combat aircraft and jet trainers are significantly larger than those of its European allies (see Table 16). All of those foreign inventories except the FRG's are composed primarily of domestic or joint designs.

Combining domestic markets with designed units in foreign inventories results in "total markets," shown in Fig. 23. That of the United States exceeds that of each major Western European nation by at least five times. Even when aggregated, Western European "total markets" are less than 60 percent that of the United States.

With this picture as a backdrop it is possible to gauge whether it is reasonable to fear that collaboration with the United States would result in a net loss of business. Estimating the size of the market that would be foreclosed by the United States is fraught with difficulties: The proper nations must be identified, their future needs must be accurately projected, Western European disagreement with the U.S. position must be assumed, and Soviet actions must be predicted. Nevertheless, with some conservative assumptions, a rough measure is obtainable.

Table 17 lists ten potential embargoed nations, along with the size of their combat and jet trainer aircraft inventory. (This list is *illustrative*; it is not intended to be predictive.) If one assumes that (1) these nations will replace 40 percent of their current inventory on a one-for-one basis in the 1990s,[89] and (2) the Soviet's market share will remain the same (34 percent), the potential market for all western suppliers totals 761 aircraft.[90] Assuming that only the United States declines to sell to these nations (a dubious proposition), that total represents the potential loss that Western European nations, *taken together*, would face; the losses of individual nations, which could not hope to achieve a monopoly, would be fractions of that total.

By contrast, the potential U.S. markets, consisting of the U.S. services and all present recipients less those on the hypothetical embargo list and the three major European producing nations (France, Great Britain, and the FRG), would be many times larger. Assuming that the United States will replace 40 percent of the U.S.-supplied portion of their inventories, the potential U.S. market is about 5000 aircraft. This is probably an order of magnitude greater than the potential market for any single European nation.

The importance of the large market share differential is that it might permit effective compensation for potential "closed-off" sales. Moreover, there are various approaches to such compensation.

- *Buy European:* The U.S. Navy's selection of a European design (the Hawk) for its new trainer requirement could involve 250 to 300 aircraft.
- *Share the U.S. domestic market:* 10 percent (the EPG's share the U.S. F-16 program) of projected future needs (calculated as above) represents about 300 aircraft.

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[87]Only three nations have tactical aircraft inventories composed exclusively of French aircraft, Ireland, Cameroon, and Senegal. These three inventories total 16 aircraft.

[88]Six nations (not including France and West Germany) have ordered a total of 245 Alpha Jets.

[89]We made this assumption to determine the approximate inventory turnover in the 1990s. It is based on experience in the 1970s.

[90].4 × 2883 × .66 = 761.

Table 16

COMPOSITION OF DOMESTIC INVENTORIES OF COMBAT AIRCRAFT AND JET TRAINERS[a]

		Design Origin (Percent of Total)		
Nation	Units	Domestic Origin	Joint Design	Foreign Design
United States	8385	98.9	0.0	1.1
France	1069	70.9	12.9	16.2
United Kingdom	1024	64.1	23.3	12.6
Italy	655	54.9	15.3	29.8
Sweden	940	100.0	0.0	0.0
FRG	1212	0.0	31.8	68.2

[a]Including orders.

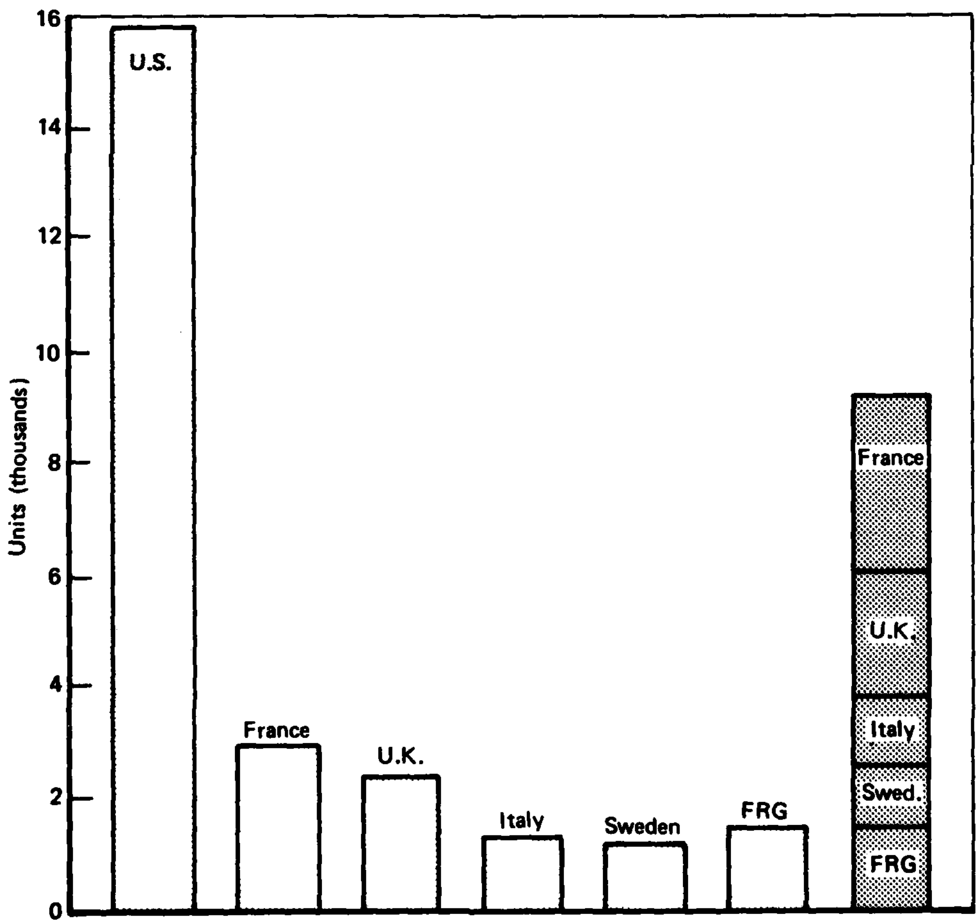

Fig. 23—Total combat aircraft and jet trainer markets (by designer-nation)*

* Domestic inventories plus designed units in foreign inventories, including orders.

Table 17

Hypothetical List of Potential Embargoed Nations and Characteristics of Their Combat Aircraft and Jet Trainer Inventories

Potential Embargoed Nation	Current Inventory	Percent Western Designs	Percent On Order
Chile	116	100.0	0.0
Ecuador	52	100.0	26.9
Ethiopia	153	30.1	0.0
Iran	456	100.0	0.0
Iraq	398	18.3	9.0
Libya	456	92.5	42.1
Taiwan	516	100.0	9.3
South Africa	235	100.0	0.0
South Yemen	100	0.0	0.0
Syria	401	0.0	3.0
TOTAL	2883	66.4	

- *Share the U.S. foreign markets:* 20 percent of U.S. projected foreign markets represents over 400 aircraft,
- *Refrain from competing for some markets:* Conceding the Taiwanese or Swedish markets to Western European suppliers, for instance, might involve 200 to 250 aircraft each.

These options are listed to show that a collaborator of the United States stands to share—in a number of ways—a potentially vast market for combat aircraft and jet trainers. In fact, its share as a collaborator could greatly exceed any sales forgone as a result of U.S. arms export policies. There is probably the need for an additional American demonstration of good faith to show that a portion of the base market indeed is available to partner nations. However, this analysis should be adequate to overcome any hesitancy based on economic fears.

This and the preceding section have laid the groundwork for a better understanding of multinational coproduction by examining basic U.S. and European differences and the implications for program outcomes of programmatic responses to those differences. This general examination has relied on experiences accumulated in a variety of collaborative programs. The next section contains a narrower examination of the implications of European participation in the coproduction of the U.S. Air Force F-16 fighter aircraft, permitting a much more detailed investigation of coproduction's effect on program costs and schedules.

IV. COST AND SCHEDULE IMPLICATIONS OF EUROPEAN PARTICIPATION IN THE F-16 PROGRAM

INTRODUCTION

One of the most ambitious coproduction efforts ever attempted, the F-16 program, features the concurrent production of airframe, engine, and avionics components in five countries and aircraft final assembly in three. After the program gathers momentum, almost every aircraft will contain parts produced in each of the participating nations.[1]

What evolved as a complex program actually began as a simple one. After years of debate and many small paper studies, Deputy Secretary of Defense David Packard announced in the fall of 1971 that the U.S. Air Force would begin a Lightweight Fighter (LWF) program.[2] Intended principally to demonstrate the feasibility of several recent technological advances (including automatic variable camber, relaxed static stability, fly-by-wire controls and composite structures), the program began with two contractors building and helping test two prototypes, but with no official commitment to production or even full-scale development (FSD).[3] As recommended by most prototyping studies, the Air Force adopted various simplifying management policies, including minimal government oversight and documentation (the main substance of the Request for Proposals was only ten pages long, for instance).

In April 1972, three months after it issued Requests for Proposals, the Air Force selected General Dynamics and Northrop over three other competitors. Their designs differed in several important respects including:

- *Number of engines.* The General Dynamics YF-16 used a single F100 engine (developed for the F-15), while Northrop's YF-17 used two newly developed J101s.
- *Cockpit design.* The YF-16 featured a unique "bubble" canopy and tiltback seat; the YF-17 had a conventional two-piece canopy and a fairly standard seat.
- *Flight control system.* The YF-16 featured a fly-by-wire control system, relaxed static stability, and a special side-mounted "force stick." The YF-17 used fly-by-wire control of the ailerons, but conventional mechanical linkages to the tail surfaces, and a standard autostabilization system.

Both designs were fairly small and lightweight (21,400 lb gross takeoff weight for the YF-16 and 24,760 lb for the YF-17). Construction periods, established by the contractors, lasted about two years. The YF-16 flew first in February 1974, followed by the YF-17 four months later. Both designs were slated for one-year test programs.

Although the prototype program began with no formal commitment to develop a missionized version of the LWF, support for such a decision grew rapidly. In May 1974, the Air Force submitted to the Office of the Secretary of Defense its Program Objective Memorandum,

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[1] U.S. program cost alone exceeds $8 billion (1975 dollars).

[2] U.S. Senate Committee on Armed Services, *Advanced Prototype, Hearings*, 92d Cong., 1st Sess.; U.S. House of Representatives, Committee of Armed Services, *Use of Prototypes in the Development and Procurement of Weapon Systems, Hearings*, 92d Cong., 1st Sess.

[3] For more information on the Lightweight Fighter prototype program, including an assessment of how the prototype phase contributed to the successful completion of F-16 full-scale development, see Giles K. Smith et al., *The Use of Prototypes in Weapon System Development*, The Rand Corporation, R-2345-AF, March 1981.

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MULTINATIONAL COPRODUCTION OF MILITARY AEROSPACE SYSTEMS.(U)

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which proposed an augmented, 26-wing, full-strength active force structure to include the Air Combat Fighter (ACF)—a missionized version of one of the LWF designs.

Also in early 1974, four NATO nations—Belgium, Denmark, The Netherlands, and Norway—formed a consortium to choose a common replacement for their F-104Gs. Although each had earlier considered individual purchases, the consortium invited the United States, France, and Sweden to submit bids for a common purchase of 348 aircraft. The Swedish entry was the Saab 37E Viggen, said to be favored by Denmark, which already operated the Saab/Scania 35 Draken. France proposed Dassault's F1E, which Belgium and The Netherlands had nearly purchased earlier. The United States, in the process of deciding to produce one of the LWF designs,[4] offered the YF-16 and the YF-17 and agreed to accelerate its own source selection to permit a consortium selection in early 1975.

Aggressive marketing and promotion, matched by careful deliberations, continued throughout the remainder of 1974. In August, the Air Force awarded General Dynamics and Northrop "transition" contracts to enable them to prepare full-scale development proposals. On 13 January 1975, the Air Force announced the selection of the F-16 and awarded FSD contracts to General Dynamics and (as an associate contractor) Pratt & Whitney, producer of the F100 engine. Within five months, the European consortium had indicated its preference for the F-16 over the European entries.[5]

Representatives of the United States and the four European Participating Governments (EPG) signed a formal Memorandum of Understanding in late May and early June 1975.[6] The MOU set forth the basic principles governing the program, including the aspect that almost certainly was a dominant factor in the EPG's selection of the F-16, namely, the coproduction arrangement.

The U.S. government agreed to sell 348 aircraft to the EPG (see Table 18). The MOU contained an estimated program charge in the form of a Not-To-Exceed (NTE) price. That price[7] was broken down as follows:[8]

Airframe	$3.450 million
Engine	1.445 million
Radar	.372 million
GFAE	.153 million
FSD share (i.e., R&D recoupment) (including engine)	.470 million
Industry management	.005 million
Duplicate tooling	.196 million
Unit price	$6.091 million

The overall NTE price does not include such support items as initial spares, aerospace ground equipment, and training. The MOU charged the five-nation F-16 Steering Committee with

[4]The official decision—represented by the DSARC IIIA milestone—was not made until 1977. The tendency for important decisions in multinational programs to be made outside normal decisionmaking channels was discussed in Section III.

[5]For more information on the deliberations of the Europeans, see Phillippe Grasset, "The F-16 Choice—A Lesson for the Future?" *Interavia*, August 1975, pp. 883-886.

[6]*Memorandum of Understanding Between the Government of the United States and the Governments of Belgium, Denmark, The Netherlands and Norway Relating to the Procurement and the Production of the F-16 Aircraft* (hereinafter referred to as F-16 MOU).

[7]Expressed in January 1975 dollars and consisting of NTE prices defined in U.S. government contracts with General Dynamics and Pratt & Whitney, estimated prices for the radar and government-furnished aerospace equipment (GFAE), and a firm share of FSD costs.

[8]F-16 MOU, Section C, paragraph 14. There is some dispute over the legal meaning of an NTE price, but that issue is beyond the scope of this analysis.

Table 18

PLANNED PURCHASES OF PARTIES TO F-16 MOU

	F-16As[a]	F-16Bs[b]	Total
United States	553[c]	97[c]	650
Belgium	104	12	116
Denmark	46	12	58
Netherlands	80	22	102
Norway	60	12	72

SOURCE: F-16 MOU, Section D, paragraph 21a.

[a]Single-place model.

[b]Two-place model.

[c]Approximate quantities; planned total U.S. buy of 650 aircraft, approximately 15 percent of which were to be two-place models.

developing procedures based on the principle that "neither the U.S. contractors nor any European subcontractor shall realize financial benefit nor incur financial loss by reason of" exchange rate fluctuations.[9]

The Department of Defense agreed to stipulate in the development and production contracts with General Dynamics and Pratt & Whitney that—on the condition that "reasonably competitive" terms are offered—the contractors shall place with the EPG industries:

- 10 percent of the procurement value of the 650 F-16s being purchased by the U.S. Air Force;
- 40 percent of the procurement value of all F-16s purchased by the EPG;
- 15 percent of the procurement value of all "third-country" purchases of the F-16.[10]

The effect of this assurance was that 58 percent of the initial EPG F-16 procurement would be offset by production work placed with industries in the four consortium nations,[11] even if there were no third-country sales. The commitment was to be fulfilled primarily with work within the F-16 program itself,[12] although any shortfall was to be made up with other "compensatory work of comparable technology." The participating governments were to attempt to distribute work proportionally among the consortium nations according to the procurement value of each country's initial buy. Satisfying this principle represented a considerable challenge, because of the four consortium countries, only The Netherlands and Belgium had well-established aerospace industries offering a reasonably broad spectrum of production capabilities. The condition that the terms offered by EPG industry be "reasonably competitive" was described but not defined in an annex to the MOU.

[9]F-16 MOU, Section C, paragraph 15.

[10]F-16 MOU, Section L, paragraph 36.

[11]F-16 MOU, Section L, paragraph 38. This figure was derived from the following equation: $100 \times [(.1)(650) + (.4)(348)]/348 \cong 58$.

[12]The MOU did not allow transfer of the following technologies: (1) fire control computer software, (2) electronic warfare equipment, (3) certain elements of the main propulsion system, including high-pressure nozzle vanes, and high pressure rotating turbine stages, and (4) integrated circuitry and processor elements of the look-down coherent pulse doppler radar. F-16 MOU, Section F, paragraph 26.

After the signing of the MOU, U.S. industry began the lengthy iterative process of soliciting bids and placing work (through firm fixed-price contracts) in the four European nations (the general contractual arrangement is shown in Fig. 24). The resulting distribution of work, displayed in Table 19, involves 28 major EPG subcontractors participating in 50 major manufacturing or assembly operations. The production shares of each nation (and their composition) are shown in Fig. 25. The distribution of airframe, engine, and avionics work is one manifestation of the different capabilities of the participating European nations.

The arrangements produced an intricate production flow plan (see Fig. 26). Two final assembly lines in Europe—one at Fokker in The Netherlands, the other at SABCA/SONACA in Belgium—are each scheduled to deliver one-half of the EPG's 348 aircraft by the end of 1984. Various parts and subassemblies will travel in criss-crossing supply lines to support production on both sides of the Atlantic.[13] The quantity split between U.S. and European contractors varies from one production task to another.

This section examines various issues relating to the complex division of responsibilities, beginning with the extra schedule considerations added to the program by the European participation. It also evaluates program schedule experience to late 1980. From a cost perspective, it discusses and, where possible, quantifies the incremental cost of the coproduction arrangements—to both the United States and the European consortium. The discussion analyzes the cost implications of two options for a USAF follow-on buy and concludes by addressing the question of U.S.-European price competitiveness.

SCHEDULE IMPLICATIONS

European participation in the F-16 program has introduced additional schedule considerations that would not have been present had the F-16 been a purely domestic acquisition program. In varying degrees, these considerations have influenced all program phases from source selection through deployment. Some considerations stem more from generic characteristics of European government and industry than from the unique circumstances of the F-16 program; hence, an assessment of their schedule consequences may hold useful insights for future programs as well. Addressing schedule issues from a U.S. Air Force perspective, the subsequent discussion identifies the additional schedule considerations and their underlying causes, examines how these considerations have influenced both the scheduling effort itself and the resulting pace and sequencing of events in the program and evaluates the program schedule experience to date.

Considerations Added by European Participation

In formulating and carrying out the F-16 coproduction program, the Office of the Secretary of Defense and subsequently the U.S. Air Force have had to try to balance the diverse and sometimes conflicting objectives of several of the constituencies in the five producing countries and subsequently in third countries as well. OSD policy decisions to make the program more attractive to the European consortium limited the Air Force's program scheduling options—at times introducing some elements of risk (e.g., to meet the commitment for early

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[13]Only the United States has the capability to produce every part of the weapon system (with the exception of the Head-Up Display, which is supplied by Marconi Avionics Limited of Great Britain).

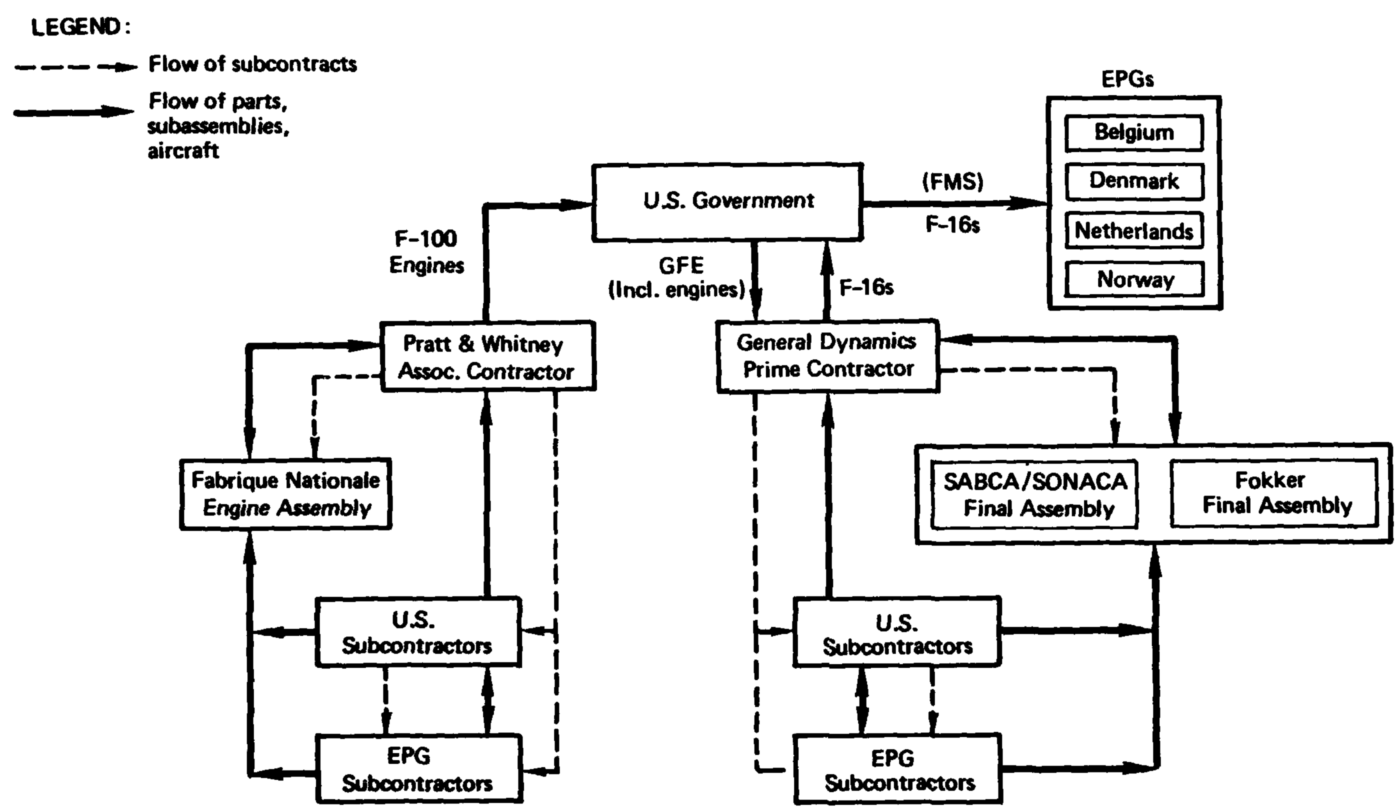


Fig. 24—General F-16 coproduction arrangement

Table 19

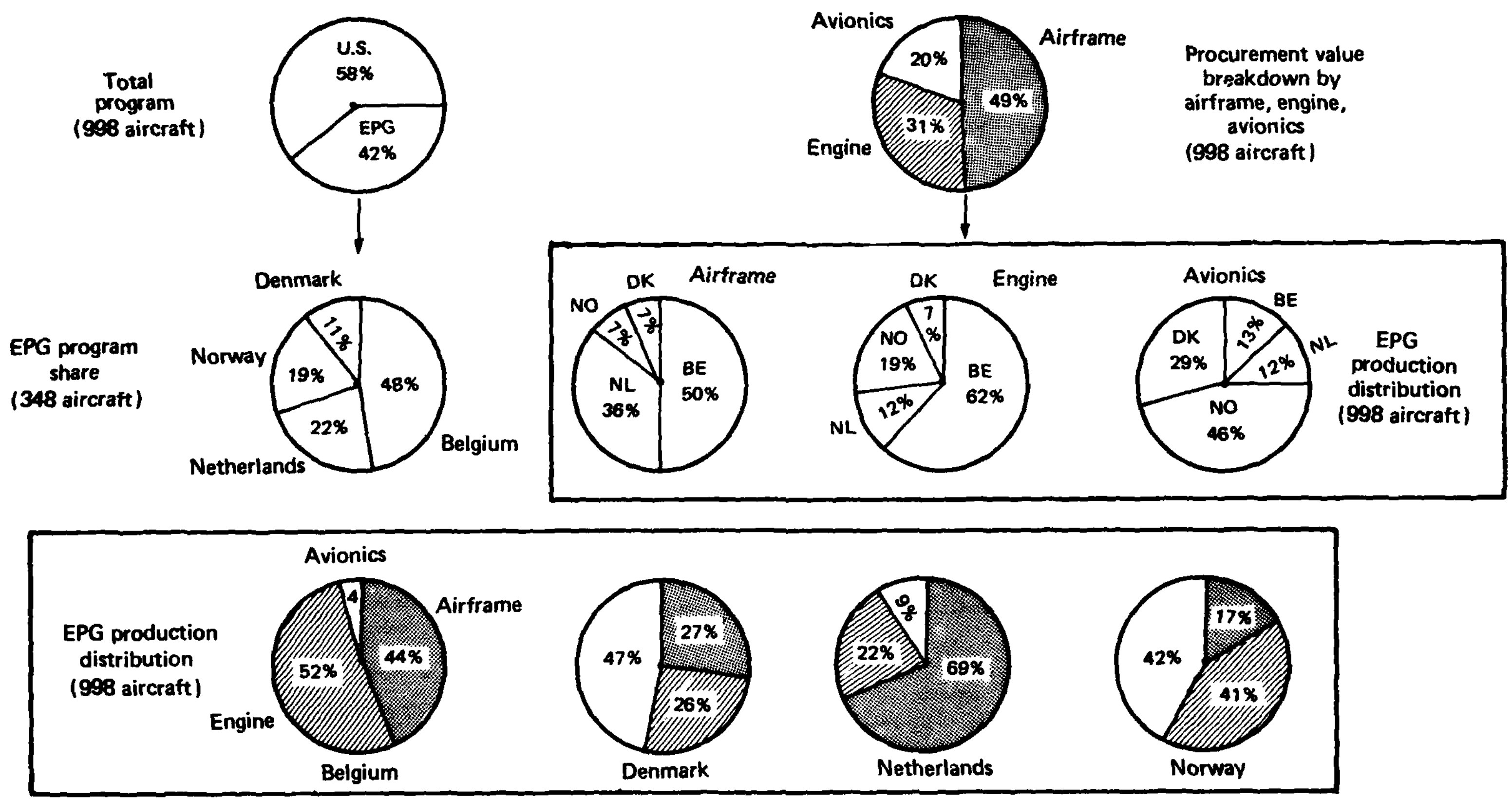
U.S. AND EUROPEAN MANUFACTURERS OF COPRODUCED ITEMS

		European Manufacturers			
Item	U.S. Manufacturer	Belgium	Denmark	The Netherlands	Norway
Airframe					
Final assembly	General Dynamics	SABCA/SONACA		Fokker	
Center fuselage	General Dynamics			Fokker	
Aft fuselage	General Dynamics	SONACA			
Wing box	General Dynamics	SABCA			
Fin box	General Dynamics	SONACA			
Vertical fin assembly	General Dynamics		Per Udsen		
Leading edge flaps	General Dynamics			Fokker	
Flaperons	General Dynamics			Fokker	
Leading edge flap drive system	General Dynamics		Jorgen Hoyer		
Landing gears	Menasco			DAF	
Main wheels	Goodyear				Raufoss
Anti-skid brakes	Goodyear				Kongsberg
Integrated servo actuator	National Waterlift	SABCA			
Emergency power unit controller	AiResearch		DISA		
Constant speed drive	Sundstrand				Raufoss
Engine starting system controller	Sundstrand		DISA		
Heat exchangers	Hamilton Standard		Quitzau		
Inverter	Aerospace Avionics		Silcon		
Manual trim panel	General Dynamics		STD Electric Kirk		
Pneumatic sensor	Rosemount		B&W Electronics		
Fuel quantity measuring system	Simmonds Precision			Simmonds NV	
Ammunition handling system	General Electric				Raufoss/ Norcem-Plast/ Sperry-Vickers
Pylons	General Dynamics		Per Udsen		
370-gallon tank	Sargent Fletcher				Nordisk
Engine					
Assembly and test	Pratt & Whitney	Fabrique Nationale			
Inlet/fan module	Pratt & Whitney	Fabrique Nationale			
Fan drive module	Pratt & Whitney	Fabrique Nationale			
Core module	Pratt & Whitney	Fabrique Nationale			
Gearbox module	Pratt & Whitney		DISA[a]		
Turbine compressor	Hamilton Standard				Kongsberg
Augmentor and exhaust module	Pratt & Whitney			Philips	
Avionics					
Radar computer	Westinghouse	MBLE			
Radar racks	Westinghouse				NERA Bergen
Radar control panel	Westinghouse		B&W Electronics		
Radar antenna	Westinghouse			Signaal	
Chaff and flare dispenser	Tracor		DISA		
Flight control computer	Lear-Siegler		B&W Electronics		
Flight control panel	General Dynamics		STD Electric Kirk		
Fire control computer	Delco		DIG No. 1		
Radar E/O	Kaiser		NEA-Lindberg		
Head-up display					
Pilot display unit	Marconi-Elliot[b]			Oldelft	
Electronic unit, rate gyro	Marconi-Elliot[b]				Kongsberg
AF-IFF transponder	Teledyne				STK
Inertial navigation set	Singer Kearfott				Kongsberg
Interference blanker	Novatronics				G.A. Ring
Rate gyro	Northrop				Kongsberg
Stores management set	General Dynamics				Kongsberg
Generator, 40 KVA control unit	Westinghouse		Radartronics		
Channel frequency indicator	Magnavox		Radartronics		
Ice detector	Rosemount		B&W Electronics		

SOURCE: General Dynamics

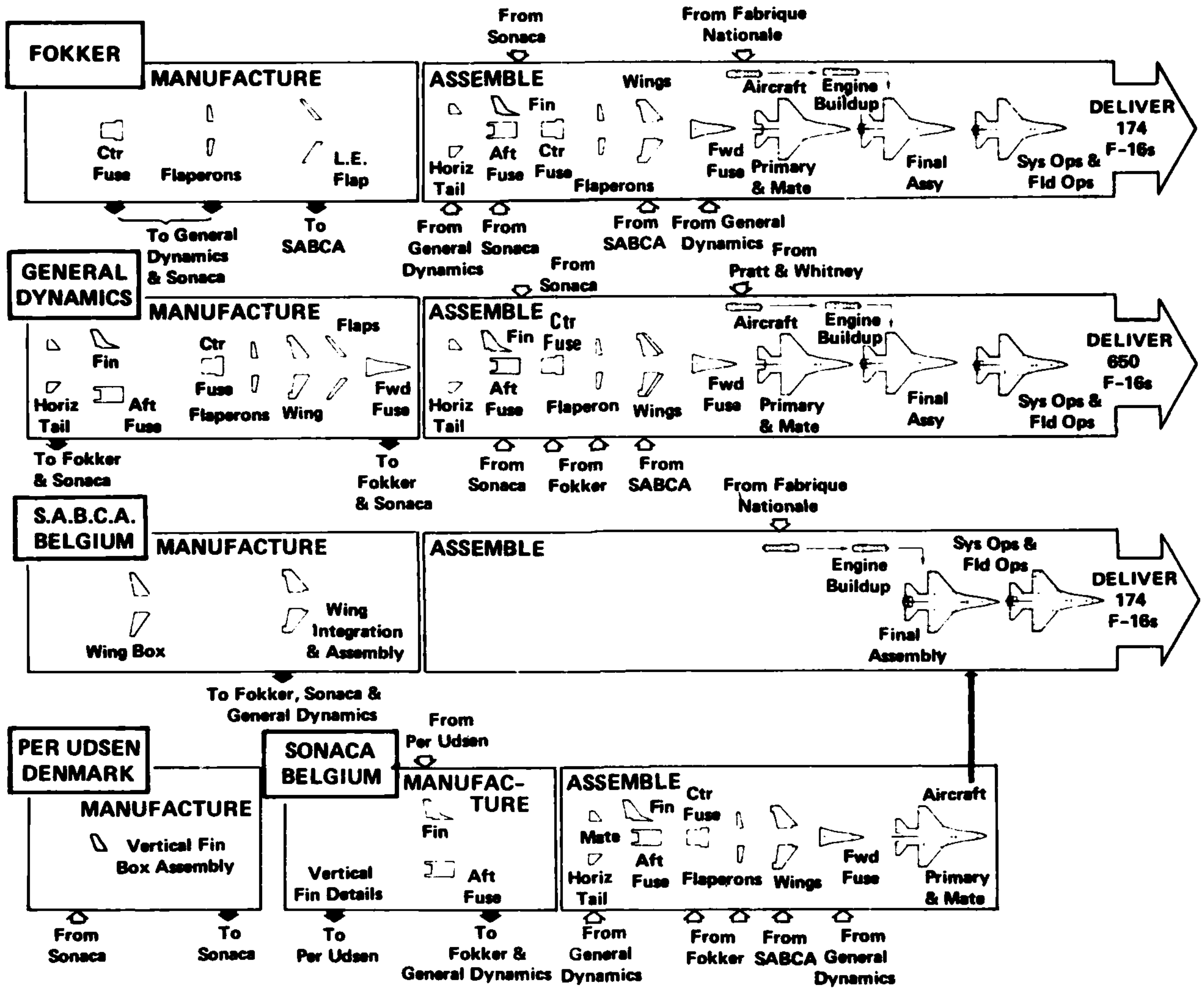
[a]Pratt & Whitney terminated its contract with DISA on 23 December 1980.

[b]U.K. manufacturer.



SOURCE: F-16 SPO

Fig. 25—Distribution of EPG production (based on procurement value)



SOURCE: *The F-16 Multinational Fighter Co-Production Program Status,* General Dynamics, August 1, 1978.

Fig. 26—Multinational production flow

European deliveries, the Air Force had no choice but to schedule concurrent development and production of several key subsystems).[14] At least five considerations, some introduced through the MOU and others introduced during implementation of the program with the European governments and industries, have contributed significantly to changing the character of the F-16 schedule. They include:

- Early delivery requirements of two European governments.
- Delays in beginning European production activities.
- Longer European lead times and manufacturing times.
- Duplication and integration of certain production operations.
- Constraints on the European ability to respond and adapt to major program changes.

Early European Delivery Requirements. In a typical national program, the acquiring service usually has the prerogative of tailoring its program schedule to satisfy its delivery requirements, subject to the usual cost and technical constraints. In contrast, the need to meet different national delivery requirements has shaped the schedules of most multinational programs, and the F-16 program is no exception.[15] Belgian and Dutch requirements for an early decision on an F-104G replacement helped crystallize and accelerate early program events, while requirements for the timely delivery of those replacement aircraft set the pace for the F-16 program.

Delays in Beginning European Production. The process of European governments and industries familiarizing themselves with regulations governing the acquisition of U.S. military equipment (e.g., the Defense Acquisition Regulation, Cost Accounting Standards, Military Standards) and the negotiation of the administrative agreements that governed the conduct of the program on the government and contractor level (e.g., MOU, Letters of Offer and Acceptance) delayed the start of European production activities.[16] After the five governments had signed the MOU in June 1975, it took 18 months longer than planned to submit and sign the LOAs, bilateral contracts between the United States and each consortium country outlining purchase and support agreements.[17] Difficulties on both sides of the Atlantic in getting European industry under subcontract contributed to the delays.[18] The European governments and contractors expressed considerable concern about termination for convenience clauses, progress payments, audit procedures, and a multiplicity of other issues that distinguish U.S. and European defense contracting. About 90 percent of the contracts had been awarded 21 months after the original target date for having all major European subcontracts signed.[19]

Subcontracting delays are just one example of the additional tasks that faced U.S. contractors in trying to identify European contractors with appropriate capabilities and the ca-

[14]The Air Force has used concurrency in many previous domestic acquisition programs as well. As a consequence there is no way to confidently ascribe all of the concurrency in the F-16 program to the multinational character of the program. However, the program framework established by OSD precluded many independent Air Force decisions about the program schedule.

[15]See the discussion of accommodating different delivery requirements on pp. 43-44.

[16]Reportedly, some production-related activities began in Europe before all contractual arrangements were finalized.

[17]U.S. GAO, *Sharing the Defense Burden: The Multinational F-16 Program*, PSAD-77-40, August 15, 1977, pp. 12-14.

[18]Some European contractors had to learn how to submit proposals that could be evaluated on a competitive basis, while some U.S. subcontractors were slow in accepting the idea of sharing production responsibilities with European industry.

[19]U.S. GAO, *Sharing the Defense Burden*, p. 11: The immaturity of some aircraft systems brought about by the pace of the program contributed to delays in nailing down the final details of the General Dynamics-USAF contract, which in turn made it more difficult to select European subcontractors.

pacity to produce items on schedule at "reasonably competitive" prices, in the parlance of the MOU. In deciding how much of the production task to prudently place in Europe, U.S. contractors had to balance price and capability considerations against the MOU's explicit 58 percent consortium offset goal. The desire of each consortium member to achieve that offset goal individually further complicated subcontracting efforts.

These kinds of subcontracting considerations introduced sizable delays in completing coproduction contracts for some parts of the weapon system—nine months in the case of the radar. Westinghouse had to restructure its entire radar coproduction plan because prices quoted by potential European coproducers were considered far too high in comparison with domestic prices.[20] The restructuring included placing more work in the Scandinavian countries to help satisfy offset goals. Given the absence of offset requirements and the presence of long-standing relationships between prime contractors and many vendors familiar with U.S. defense contracting in a competitive environment, such production startup delays are unlikely to occur frequently in purely domestic programs.[21]

Longer European Lead Times. Longer European lead times and manufacturing times are another schedule consideration introduced by European participation.[22] European production of F-16 airframes requires from six to 12 months additional lead time. Pratt & Whitney estimates that European production of F100 engines requires approximately six months more lead time than domestic production. Some radar component production lead times differ by three to 12 months. Contributing factors include differences in facility and personnel utilization, some production facility limitations in the consortium countries, differences in production rates, material ordering procedures European industry must use, shipment time to Europe, and inclement European weather conditions.[23]

European consortium manufacturers generally use their facilities fewer days during the year and fewer hours per day. General Dynamics estimates that its European airframe coproducers have approximately 16 fewer manufacturing days per year. Some of the major European radar subcontractors' plant facilities are closed two to three times more days per year than the Westinghouse-Baltimore facility. Annual summer plant closings or summer operations at reduced staffing levels account for much of the difference.

Greater use of single shift operations, a reluctance to use overtime or heavy infusions of temporary workers, and shorter workweeks contribute to a generally lower facility utilization per day in Europe.[24] For example, General Dynamics runs two full shifts and a partial third shift, whereas one of its major subcontractors in Europe, SABCA, using a 37-hour workweek, does not have a regular second shift for all manufacturing operations, although it does use two shifts for numerically controlled machine tools and milling machine operations, and for final assembly, checkout, and flight testing. Westinghouse-Baltimore runs a two-shift operation, whereas most of its European subcontractors use only a single shift. Pratt & Whitney uses a full first shift, a two-thirds second shift, and a one-third third shift; Fabrique Nationale, using a 37-hour workweek, runs a second shift for assembly and test operations

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[20]U.S. GAO, *Sharing the Defense Burden*, p. 12.

[21]See pp. 111-114 for additional discussion of achieved offsets.

[22]Used in this context, lead time encompasses the calendar time from the order for an item to its delivery. Manufacturing time, or production span time, refers to the calendar time to accomplish a particular fabrication or assembly task.

[23]Differences in lead times would be more striking were it not for the substantial American production content of each European assembled F-16 airframe and F100 engine.

[24]This pattern of operations does not necessarily represent European corporate preferences, but rather their response to the operational constraints regarding workforces imposed by national laws and customs, and influential unions and other worker associations.

and some capital-intensive machine tool operations. Other engine subcontractors, such as Philips, operate only a single shift. These shift policy differences generally translate into more calendar time for comparable manufacturing activities in Europe.

U.S. contractors also report observing greater absenteeism at some of their European subcontractors than what they typically find in the United States. The lower scale of usual production activities in Europe generally means that consortium firms, while having highly skilled and qualified personnel, do not have as much personnel depth and hence lack the flexibility of a larger contractor such as General Dynamics in compensating for absences of key individuals.

European airframe manufacturers also cite certain facility limitations that make it difficult for them to match U.S. manufacturing times, even when using similar equipment. For example, while General Dynamics and SABCA use comparable tools to manufacture F-16 wing sets, floorspace limitations at SABCA's Haren facility make the process of advancing the wings along the assembly line more awkward and time consuming than in Fort Worth. Moreover, after SONACA performs mating operations, workers must tow aircraft across the runway to the plant of a second contractor, SABCA, to complete production activities, whereas General Dynamics just moves aircraft to the next work station in the same plant. With more floorspace, General Dynamics can and does also maintain a larger buffer inventory of parts for problems that might develop during assembly than European contractors. The unified production facility at Fort Worth provides a greater reservoir of production support to deal with problems than is available with the distributed manufacturing approach in Europe.

Differences in the scale of production can also contribute to differences in U.S. and European manufacturing times because of learning during production, although U.S. manufacturers do not produce all aircraft components in greater quantities.[25] However, for one of the more time consuming production tasks, aircraft final assembly, according to current plans General Dynamics will ultimately be delivering 15 to 19 aircraft per month to satisfy U.S., Israeli, and Egyptian requirements, compared with three aircraft per month per assembly line in Europe.[26]

Program participants cite several other factors that contribute to longer European lead times, some of which were anticipated in setting the original production schedule. Inclement weather tends to lengthen the time required to accomplish field operations in Europe before delivery. International shipment of materials and parts can take somewhat more time than interstate shipment. Finally, differences in the procedures for ordering materials also contribute to longer European lead times. U.S. contractors order materials directly from U.S. vendors, but European subcontractors must frequently order through the U.S. vendor's European representative. This can add a month or more to the lead time for a European purchase. Moreover, some U.S. vendors have been reluctant to obtain the export license needed to sell their items in Europe, forcing some European subcontractors to order materials through their associated contractors in the United States, further lengthening European lead times.

Duplication and Integration of Production Operations. To satisfy European objectives relating to employment, technology transfer, maintenance of a production base, creation of an indigenous overhaul capability, and participation in production for the domestic U.S. market and third-country sales, the F-16 program features integrated coproduction feeding three final assembly lines. Although most recent U.S. aircraft programs feature the dispersed

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[25]See pp. 114 ff. for more details about U.S. and European production quantities.

[26]*Management Information Notebook*, F-16 Multimission Fighter System Program Office, November 30, 1980, p. 6. General Dynamics has a planned capacity to produce as many as 45 aircraft per month.

production of individual components, subassemblies, or assemblies, they rarely feature the duplication of the same production operation at more than one location, and even more rarely the duplication of final assembly lines (the B-47, B-52, and F-100 programs represent notable exceptions) fed by multiple suppliers. The latter type of arrangement obviously introduces a host of schedule issues not found in more conventional domestic programs, such as the coordination and tracking of production at numerous European and U.S. locations to insure the timely completion and transmittal of the appropriate parts meeting specifications to U.S. and European assembly lines for integration with the remainder of the weapon system.

Constraints on Making Program Changes. Finally, European participation has forced U.S. program participants to weigh more carefully the ramifications of schedule changes that could affect production activities and delivery schedules in five countries. Indeed, the MOU explicitly pledges that "the parties hereto are determined to keep all program changes to a minimum."[27] The receptiveness, responsiveness, and adaptability of European governments and contractors to schedule changes differ markedly from their American counterparts for a variety of reasons, including differences in the scale of production, the lack of a substantial residual unused production capacity, significant constraints on manipulating work forces, particularly severe resource constraints, different budgeting procedures, and the prominent position the F-16 program occupies in the continuing political dialogues with each of the four consortium countries.

Consequences of European Participation

The manner in which events unfolded leading to the decision to develop and produce the F-16 in a multinational context illustrates how the opportunity for a large foreign aircraft sale led OSD to deviate from formal DSARC decision guidelines and how the Air Force, to satisfy commitments made on the political level, had to accept certain program risks it might have avoided in a strictly national program. However, there may have been positive schedule consequences as well. Schedule considerations added by European participation seems responsible for:

- Increasing the general pace of all program phases.
- Contributing to concurrency in development and production activities.
- Increasing the need for early U.S. contractor support of European industry.
- Increasing the complexity of the production flow and change process.
- Imbuing the program with more stability than a purely domestic program.

Source Selection Phase. The requirement for an early decision in Belgium and The Netherlands on an F-104G replacement (1) accelerated flight testing of the Air Force's LWF prototypes and (2) hastened the source selection decision and the initiation of full-scale development of an Air Combat Fighter. Originally, non-parallel, moderately paced 12-month test phases to gather information about LWF technology with the YF-16 and YF-17 prototypes were scheduled to conclude by June 1975 (see Fig. 27). Events, however, did not unfold in this manner (see Table 20), for by June 1974, OSD accelerated the test program to support a planned April 1975 source selection decision for the full-scale development of a missionized LWF or ACF derived from one of the LWF candidates.[28]

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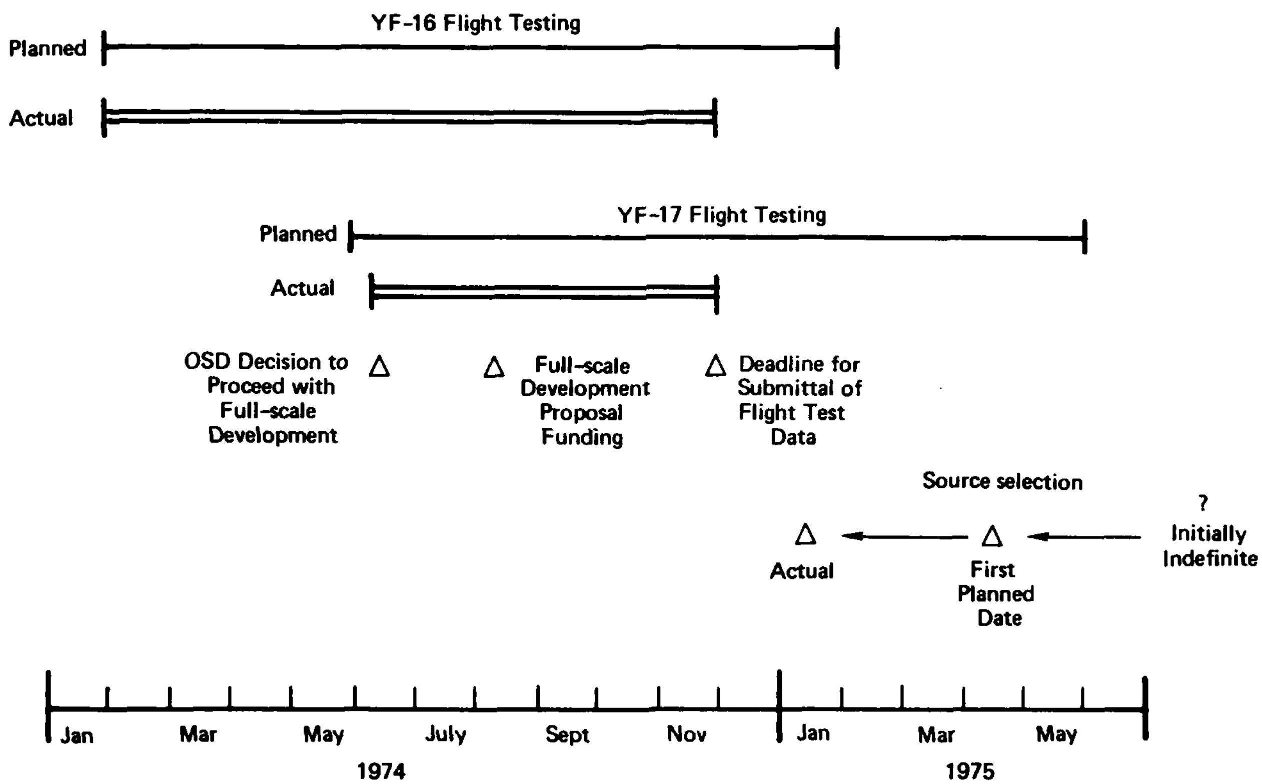
[27]F-16 MOU, Section B, Paragraph 7.

[28]Donald E. Fink, "U.S. Offers Europe Offsets on Fighter," *Aviation Week & Space Technology*, August 5, 1974, p. 13.



SOURCES: Fink (1974a), pp. 12–13; Fink (1974b), pp. 16–17; Smith and Friedmann (1980), pp. 65–68.

Fig. 27—Acceleration of prototype testing and source selection

Table 20

Chronology of Events Leading to Full-Scale Development and Production of the F-16

Date	Event
January 1974	First flight of YF-16.
April 1974	Secretary of Defense announces in letter to Congressional leaders that Pentagon is seriously considering full-scale development and production of an Air Combat Fighter.
May 1974	Tactical Fighter Modernization study group recommends reasoned and sequenced development and procurement program.
June 1974	OSD makes formal decision to proceed with full-scale development of a lightweight fighter. Source selection set for April 1975.
June 1974	First flight of YF-17.
July 1974	European consortium informs U.S. officials of Belgian and Dutch decision deadline of end of 1974.
July 1974	Secretary of Defense makes written commitment to European Multinational Fighter Committee that U.S. will make source selection by January 1, 1975, and that U.S. will produce aircraft and deploy it in Europe.
August 1974	Contracts awarded to General Dynamics and Northrop to transition from LWF to ACF.
September 1974	Secretary of Defense makes commitment to Europeans to begin full-scale development by mid-January 1975 and sets delivery dates to USAF and Europe. DoD also offers coproduction plan and announces it will buy 650 ACFs.
January 1975	Secretary of Defense approves F-16 source selection. Contracts awarded to General Dynamics and Pratt & Whitney.
March 1975	DSARC II meeting.
April 1975	Milestone II decision.
June 1975	Memorandum of Understanding signed.
June 1976	EPG long lead production decision ("mini-DSARC").
January 1977	DSARC IIIA.
October 1977	DSARC IIIB.

SOURCES: *Aerospace Daily,* April 30, 1974; *Air Force,* June 1974; U.S. Senate, Committee on Armed Services, Subcommittee on Tactical Air Power, *FY 1976/197T DoD Appropriation Authorization Act,* 94th Congress, 1st Session, Part 9, p. 4599; Fink (1974a), p. 13; (1974b) p. 17; U.S. Congress, Senate, Fiscal Year 1978, Testimony of Major General James Abrahamson, March 1977, pp. 4278-9.

Although OSD seems to have made the decision to incorporate an ACF in the USAF inventory that was independent of European interest in the aircraft, the European consortium's interest in the aircraft and most particularly a stated Belgian and Dutch requirement to decide on a F-104G replacement before the end of 1974 contributed to a further acceleration of the source selection decision.[29] The Pentagon sought to accommodate the European requirement by advancing the source selection decision to January 1975, as early as it thought prudent.[30] Both contractors intensified flight testing to meet the compressed schedules (see Fig. 27). Because funding of full-scale development proposal preparation began in early August 1974, after six months of YF-16 flight testing and only two months of YF-17 flight testing, the contractors apparently initiated a significant amount of critical work related to full-scale-development without the benefit of very much data from the flight test programs. The schedule compression, at least partly a result of European consortium

[29]While the LWF program was underway the Air Force Chief of Staff chartered a study to examine alternative tactical fighter force modernization options, including consideration of how missionized LWF designs could augment USAF tactical forces. The study, completed in May 1974, reportedly expressed the view that the introduction of the LWF was not urgent and recommended a reasoned and sequenced development and production program for a missionized LWF.

[30]Fink (1974), p. 17.

deadline, did not hamper information generation in the prototype program or bias the source selection.[31]

Ironically, after setting the early deadline, the four European countries did not formalize their commitment to the F-16 in the form of the Memorandum of Understanding until June 1975, five months after the Secretary of Defense had announced the source selection decision and had awarded full-scale development contracts. The reasons for this delay illustrate the interplay of diverse national considerations in a multinational program. In Denmark, an election had just occurred, and officials had not drawn up positions on defense spending. In Belgium, the idea of collaborating with the United States rather than with the French firm of Dassault-Breguet (a shareholder in SABCA with Fokker-VFW) became a hot political issue. Indeed, the very idea of government spending on the project inspired political protests. The Norwegians and the Dutch had previously procured Northrop F-5A/B aircraft and expressed some preference for Northrop's YF-17 twin-engine design. In addition, Northrop was a shareholder in Fokker-VFW, the only airframe firm in The Netherlands.[32]

The tendency to prefer an aircraft with the latest technological features, even if it has just begun flight testing, may contribute to similar schedule compression in the future. Although this compression had no apparent adverse effects on the F-16 source selection process, subsequent acceleration of development and production activities introduced elements of risk into the program schedule.

Development and Production Phases. During development and production, schedule considerations brought about by European participation contributed to (1) an early production commitment, (2) concurrency in the development and production of the airframe and certain key subsystems, (3) greater scheduling complexity, and (4) more U.S. contractor support of European coproducers early in the program. European delivery requirements and the characteristically longer European lead times and manufacturing times forced an acceleration of the U.S. production decision. A "mini-DSARC," held seven months before formal DSARC IIIA proceedings for the Air Force program, gave the go-ahead to begin production activities for European long-lead items (see Fig. 28). Formal DSARC IIIA long-lead production go-ahead occurred much sooner after the award of full-scale development contracts than in the F-15 program (e.g., ten months sooner for the airframe, seven months for the engine adapted from the F-15 application, 11 months for the radar, and three months for the avionics intermediate shop equipment).[33] One could effectively argue that the mini-DSARC decision to proceed with long-lead European production activities seven months before DSARC IIIA foreclosed any real option not to proceed at a subsequent date, given the international ramifications. In this context, the rapid move from the start of development to a production commitment is particularly striking.

In giving the long lead production go-ahead, the DSARC panel placed considerable faith in the airframe and engine performance demonstrated by the YF-16 prototypes, the additional four-and-one-half years of F100 engine experience accumulated in the F-15 program, and the performance demonstrated by a prototype of the Westinghouse radar tested in an F-4. Table 21 indicates that at the time of the initial production decision, the F-16 program had

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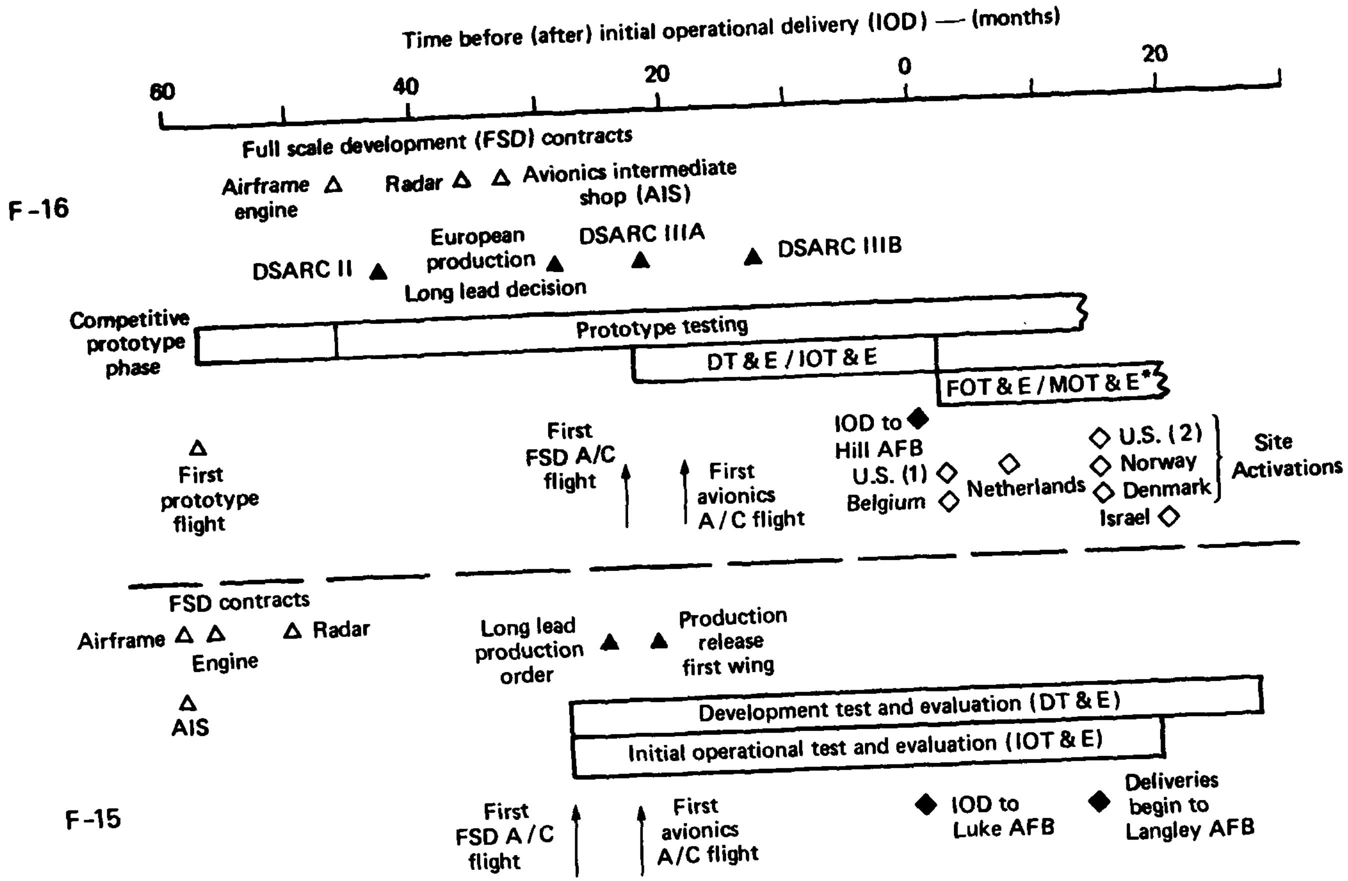
[31]Giles K. Smith et al., *The Use of Prototypes in Weapon System Development*, The Rand Corporation, R-2345-AF, March 1981.

[32]"F-16 Decision Accelerates Drive for Four-Nation Consortium Buy," *Aviation Week & Space Technology*, January 20, 1975, p. 22. Fokker and VFW are now separate firms.

[33]U.S. Senate, Committee on Armed Services, *DoD Appropriations Authorizations Act, 1978*, Testimony of Major General James Abrahamson, March 1977, pp. 4278-4279.



SOURCES:
F-16 Multimission Fighter System Program Office, *Management Information Notebook* (Various Issues); F-16 Selected Acquisition Reports (Various Dates); U.S. Congress, Senate, Fiscal Year 1978, Testimony of Major General James Abrahamson, March 1977, p. 4278; GAO, *Sharing the Defense Burden, p. 12;*
F-15 Selected Acquisition Reports (Various Dates); *F-16 Lessons Learned Study Report,* Defense Systems Management College, June 20, 1978. U.S. Congress, Senate, Fiscal Year 1977, Testimony of Major General Robert Mathis, March 1976, pp. 5077-5081.

* Follow-on operational test and evaluation/multinational operational test and evaluation.

Fig. 28—Comparison of F-15 and F-16 program events

Table 21

FLIGHT TEST HOURS ACCUMULATED AT KEY PROGRAM MILESTONES

	Approximate Total Flight Test Hours as of		
Program	DSARC IIIA or Equivalent	DSARC IIIB or Equivalent	Initial Operational Delivery
F-16	1000 (987)[a]	1400	2900 (1200)
F-15	100	275	3200
A-10	700 (700)	2200	2200 (1100)

SOURCES: Personal communication with Major Charles Core, F-16 SPO, January 1980; Col. George Hupp, *A-10 Initial Operational Test and Evaluation, Phase 2 Test Report,* AFTEC-TR-76-104, May 1976, pp. 11, E-1, E-2; Col. George Hupp, *A-10 IOT&E, Phase I,* AFTEC-TR-75-104, October 1975, p. 3; Peter W. Odgers, *Design-to-Cost; The A-X/A-10 Experience,* Air War College, Air University, Maxwell AFB, Alabama, Report No. 5370, April 1974, p. 9.

[a]Hours in parentheses were accumulated by YF-16 and YA-10 prototypes.

accumulated many more flight test hours than had the F-15 and A-10 programs at a comparable point in time. However, because the full-scale development aircraft flew barely one month before the DSARC III meeting, it is unlikely that much information on its demonstrated performance was available to support the DSARC deliberations. In contrast, the average DoD program entering production at this time had demonstrated performance in about 85 percent of the operational and technical performance areas specified in Selected Acquisition Reports and had met (within 10 percent) or exceeded about 87 percent of the performance goals in those areas.[34]

To meet early delivery deadlines, program officials had to begin production activities on the airframe and several key subsystems before completing full-scale development. This concurrency introduced risks that might not have been present in a program with a more measured development pace. In the words of a former F-16 Deputy SPO Director:

> This is the most concurrent program since the ballistic missile. It means developing, producing, and putting into service aircraft in many nations concurrently and in a compressed time period.[35]

To meet delivery schedules, Westinghouse had to begin radar production before it had a qualified full-scale development system, resulting in considerable design changes to the initial production configuration and retrofitting of early units. Production components of the stores management system were delivered before the completion of development testing.[36] Development of the Avionics Intermediate Shop, a key set of test equipment used at

[34]Dews et al. (1979), pp. 19-22.
[35]Col. Delbert H. Jacobs, F-16 Deputy SPO Director, quoted in Edward H. Kolcum, "Fighter Effort Tests Collaboration Concepts," *Aviation Week & Space Technology,* March 2, 1977, p. 45-46.
[36]U.S. GAO, *Status of the Air Force's F-16 Aircraft Program,* PSAD-78-36, April 24, 1978, p. 24.

operational bases, began late, reportedly because of shortages of logistics personnel at the SPO early in the program.[37] Test requirements for the AIS have changed during development in response to changes in the production configuration of F-16 avionics. The first long-lead production option for AIS production hardware was exercised at the beginning of 1977, before its critical design review.[38] These and other examples of concurrency in the F-16 schedule are certainly not first time phenomena for Air Force programs, and it would be inappropriate and unfair to attribute all the concurrent scheduling to the multinational character of the program. Nonetheless, the program's early delivery requirements foreclosed more sequential development and production.

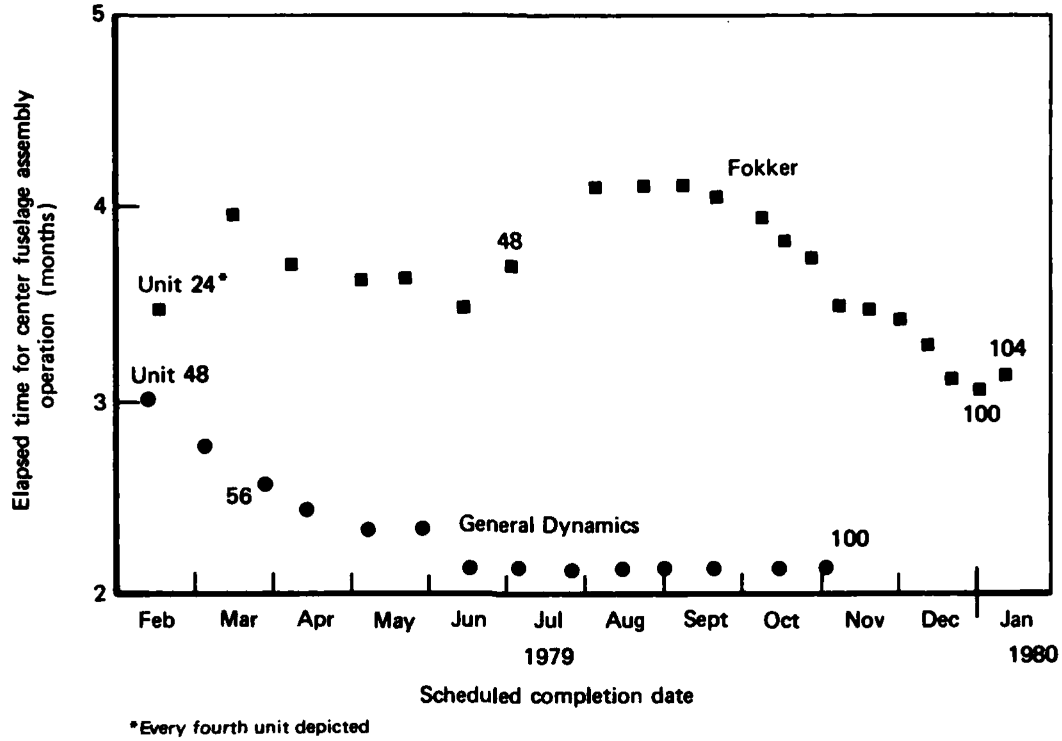
Longer European lead times and manufacturing times, coupled with production and assembly operations at more than one location, have made the scheduling process more complicated than in a typical domestic program both for original production and for the incorporation of changes on the assembly line or in the field. Differences in lead times can mean that aircraft delivered simultaneously from European and U.S. assembly lines may contain parts or major subassemblies manufactured many months apart. For example, at any given time, Fokker may require two to eight weeks more calendar time than General Dynamics for center fuselage assembly operations (see Fig. 29). Differences in U.S. and European assembly times become more pronounced (six to eight months) for major operations (see Fig. 30).[39]

The advantage General Dynamics enjoyed in accumulated production experience early in the program does not fully explain assembly time differences. Differences remain even when comparisons are made for equivalent numbers of units (e.g., assembly times for the 100th U.S. and European center fuselage differ considerably). Different plant utilization policies contribute to the fluctuations in European assembly times particularly evident in Fig. 29. When one considers the multinational parts constitution of most of the aircraft, the differences in the production rates and manufacturing times of their components, and the flow of changes generated by the concurrent development and production activities early in the program, one begins to appreciate the complexities of the F-16 schedule.

The ambitious pace of the program (set by the early delivery requirements), coupled with the delays in beginning production activities in Europe, and the constraints (e.g., shift and hiring policies) that made it difficult for European producers to gear up rapidly for production after contracts were finally signed have forced U.S. contractors to alter their production schedules to supply more parts and subassemblies to European manufacturers to keep initial deliveries on schedule (not unlike the F-104G experience). Having U.S. contractors able to manufacture each component of the aircraft has provided the Air Force with insurance against interruptions in the flow of components from European manufacturers for U.S. aircraft. Most purely European collaborative programs do not possess this level of flexibility, since, for economic and other reasons, individual European governments have generally not insisted on an indigenous production capability for all components of a weapon system.[40]

The approach used to accomplish the technology transfer and production startup varied from one European contractor to another. Some EPG contractors actually participated in the

[37] *F-16 Lessons Learned Study Report*, Defense Systems Management College, June 20, 1978, p. 5.
[38] *Management Information Notebook*, March 31, 1980, p. 143.
[39] *Management Information Notebook*, various dates.
[40] For example, the MRCA program uses local final assembly (one line each in the United Kingdom, the FRG, and Italy) but centralized major component manufacture (e.g., all forward and rear fuselage sections are manufactured in the United Kingdom, all center fuselages in the FRG, and all wing sets in Italy). "Tornado production: Centralized component manufacture—decentralized final assembly," *Interavia*, November 1977, pp. 1132.



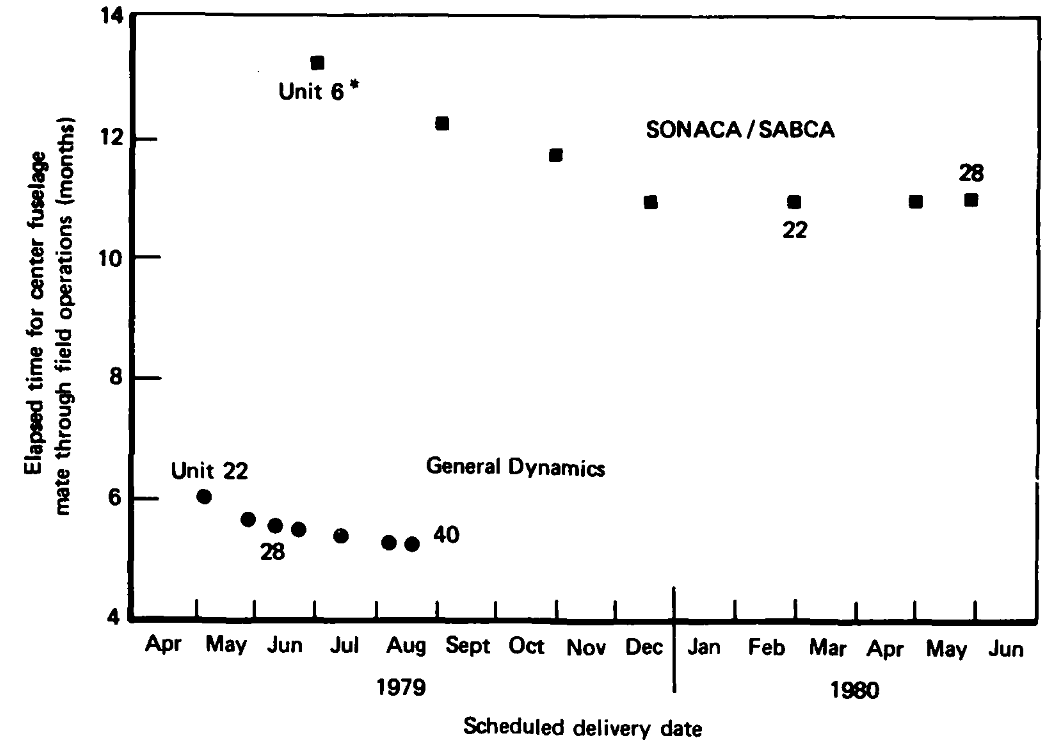
SOURCE: F-16 System Program Office, *Management Information Notebook* (various issues).

Fig. 29—Time required by U.S. and European contractors for center fuselage assembly

production of full-scale development hardware, which made the manufacture of the production article easier. For example, SABCA of Belgium gained valuable experience assembling a set of wings for one development test and evaluation aircraft using parts supplied by General Dynamics. When circumstances permit, this type of arrangement offers an attractive approach for phasing a foreign producer into a coproduction program.[41]

Deployment Phase. Base activation schedules for the F-16 and the commensurate rate of aircraft deliveries are much more ambitious than a typical domestic acquisition program. During the first year of base activations, the Air Force and the four European governments activated six bases in five countries, in contrast to a typical domestic program in which the Air Force might activate a pair of bases in the continental United States (see Fig. 31). Production rates to support deployment are two to three times that of other contemporary fighter/attack programs. In carrying out such an ambitious deployment in a program featuring significant concurrency of development and production activities, the Air Force incurs risks, particularly in the support area.

[41]Extensions to this approach might include having the foreign contractor not only assemble but also fabricate hardware for DT&E vehicles, or having the foreign contractor participate in the design and development of the article. The latter approach would give the earliest insights about production requirements. Such a codevelopment approach unquestionably carries with it benefits and liabilities—the identification of which are beyond the scope of this report.



SOURCE: F-16 System Program Office, *Management Information Notebook* (various issues).

* Selected units depicted for comparison.

Fig. 30—Time required by U.S. and European contractors for fuselage mate through field operations

Experience to Date

As of fall 1980, the F-16 program had done an impressive job of adhering to original OSD schedule milestones and production delivery schedules. With the exception of modest schedule changes to accommodate the deletion and addition of some foreign military sales, the aircraft delivery schedule has remained remarkably stable through the coproduction phase. The program has been on or ahead of schedule for eight of the ten OSD schedule milestones.[42] This represents significantly better schedule performance than the average major weapon system program in the 1970s.[43]

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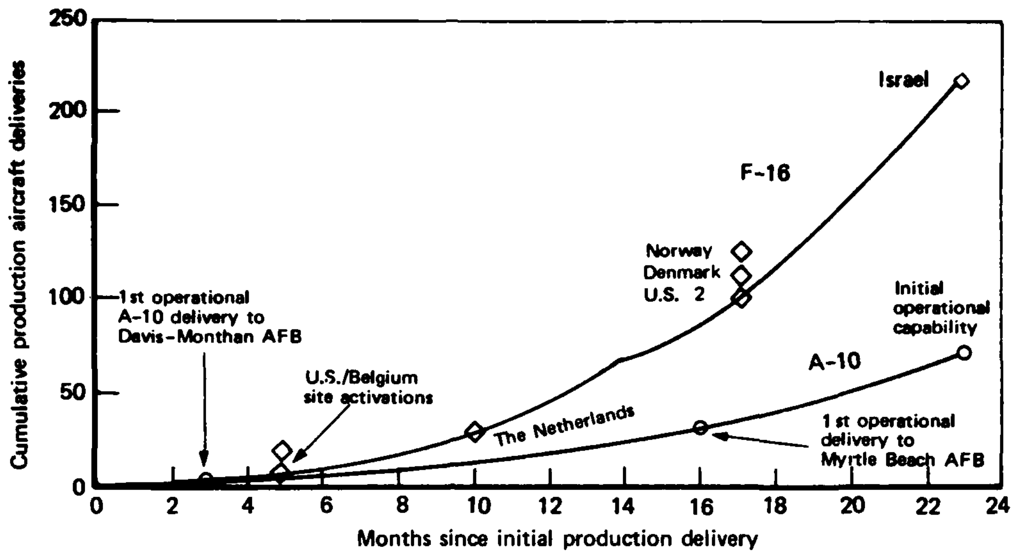
[42]Full-scale development approval (DSARC II) and full-scale production approval (DSARC IIIB) each slipped by one month, which may well have been outside of the Air Force's power to influence.

[43]In terms of the ratio of the number of months actually taken to accomplish each schedule event with the number of months originally scheduled at the time of DSARC II, the F-16 program exhibited a ratio of 1.04 while a comparable ratio for 31 major weapon system acquisitions across all three services was 1.13. Dews et al. (1979), p. 27.



SOURCE: F-16 System Program Office, *Management Information Notebook* (various issues); personal communication with Colonel Roy J. Hendricks, Director, Manufacturing Operations, A-10 System Program Office, September 28, 1979; Fact Sheet, United States Air Force, *A-10 Close Air Support Aircraft*, May 1977.

Fig. 31—Comparison of F-16 and A-10 production deliveries and deployment rates

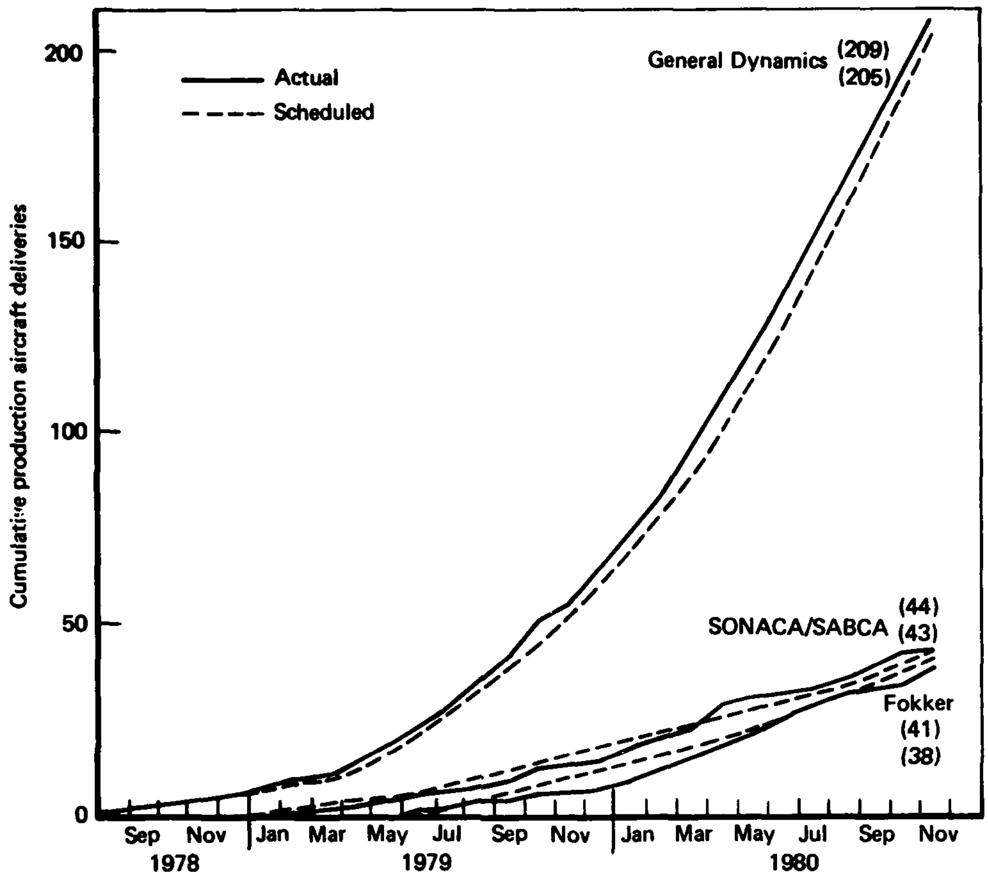
Program management has had to deal with a number of production problems, some induced by coproduction, others made more difficult because of coproduction, and still others traceable to other causes, such as vendor strikes in the United States. In responding to these problems, the SPO has generally elected to divert initial spares deliveries when necessary to keep aircraft deliveries on schedule. Although this might diminish the supportability of the system early in its operational life, it is still too early to gauge whether it has affected aircraft readiness.

Production. Through more than two of years of production deliveries, General Dynamics has consistently delivered aircraft ahead of schedule (see Fig. 32) and would probably be further ahead were it not for engine shortages unrelated to coproduction.[44] Deliveries from the European assembly lines have deviated only modestly from schedule. Through November 1980, SABCA was one aircraft delivery ahead of schedule and Fokker was behind by three aircraft and one month. Both were able to recover schedule slippage once it occurred.[45]

U.S. contractors provided early and continuing production support to effect the technology transfer and to keep deliveries from European final assembly lines close to schedule. Like previous coproduction or licensed production programs, early European aircraft have incorporated a large complement of U.S.-produced parts. The first airframe with the maximum complement of European-produced structural components was expected to be the eighth aircraft

[44] "30 F-15s to Lack Engines," *Flight International*, March 8, 1980, p. 736

[45] *Management Information Notebook*, November 30, 1980, pp. 79-81, 97.



SOURCE: F-16 Multimission Fighter System Program Office, *Management Information Notebook* (various issues).

Fig. 32—F-16 aircraft delivery experience

delivered off the SABCA assembly line in September 1979, eight months after delivery of the first European-assembled aircraft containing entirely U.S.-manufactured parts. Delivery of the first European aircraft incorporating the maximum complement of European-produced engine parts was not expected until late spring or summer 1981, more than two years after the first European aircraft delivery.[46]

The most significant airframe coproduction problem encountered thus far involves Belgium's SONACA, formerly Fairey SA, which has both manufacturing and major fuselage assembly responsibilities. A 1977 declaration of bankruptcy by its parent company forced Fairey SA into receivership as manufacturing operations continued. With the assistance of the Belgian government, a reconstituted corporation known as SONACA was formed in May 1978 to assume Fairey's manufacturing responsibilities. SONACA has had difficulty keeping on schedule for a variety of reasons, including parts shortages, lack of an effective production control system, and shortages of middle management and production workers. In an attempt

[46]The engine delivery itself was expected by early 1981. Hymer (1980).

to correct its difficulties, SONACA has made management changes, hired new workers, used overtime and second shifts, and introduced new manufacturing processes.[47]

By accelerating its tooling schedule and dipping into its management reserve, General Dynamics has taken back from SONACA the manufacturing responsibility for 17 aft fuselages destined for U.S. Air Force aircraft.[48] Although some opponents of coproduction criticize the F-16 program for wasteful duplication, this example indicates that the duplicate production arrangement has prevented significant delays in the delivery of U.S. Air Force aircraft. Some European collaborative programs (the MRCA program, for example) have suffered delays because they do not use this degree of duplication.[49]

Government and contractor officials across the consortium attribute delays in airframe production to a variety of sources, including on-the-job training of temporary workers, inclement European weather impeding flight acceptance testing, substantial engineering change activity, delays in receipt of materials from U.S. suppliers, the necessity to rework some parts, and (excepting bankruptcy) factors like those that contributed to delays at SONACA. General Dynamics personnel concede that the extended time to work out tooling bugs during the technology transfer has led to some delays. Nonetheless, with considerable U.S. backup production and efforts by consortium contractors, consortium deliveries remain very close to schedule.

Engine deliveries lagged behind schedule in 1980 in Europe and the United States, but strikes by two key domestic Pratt & Whitney vendors caused most of these delays, not coproduction difficulties. As of spring 1980, engine deliveries in Europe were 11 units behind schedule—about two months of production. This was expected to grow to about 22 engines by August 1980, a three-month schedule lag. The program response to minimize the effect of the vendor strikes has been to share engine assets across aircraft assembly lines and to divert engines originally slated for spares inventories to aircraft on the production line, presumably at some cost to the initial supportability of the weapon system. Fabrique Nationale, the only European engine contractor affected by the strike, has tried to recover from the schedule disruption by reassigning some of its work force, adding some workers, and scheduling overtime. A strike at Fabrique Nationale, however, interrupted this effort in August 1980.[50]

Pratt & Whitney had to provide considerable backup production assistance during early stages of the production effort to keep overall deliveries on schedule. Confidence has now grown in most of its European suppliers such that some will now produce greater quantities of F100 engine parts than originally planned and others might participate in commercial programs with Pratt & Whitney. In contrast, Pratt & Whitney has terminated a contract with DISA (the Danish Industri Syndikat) because it failed to meet cost and delivery responsibilities in the manufacture of the F100 engine gearbox, a low-cost but important engine component. Pratt & Whitney now produces the gearbox, which has minimized schedule disruptions brought about by DISA's continuing difficulties. They will now supply both U.S. and European assembly lines.[51]

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[47] U.S. GAO, *The Multinational F-16 Aircraft Program: Its Progress and Concerns*, PSAD-79-63, June 25, 1979, pp. 4, 5.

[48] Whether SONACA would subsequently have the opportunity to make up for this loss of production has been a subject of negotiation between General Dynamics and SONACA. *Management Information Notebook*, July 31, 1979.

[49] Generalized specification of an optimal level of production duplication seems inappropriate, given the variation of circumstances with each new program.

[50] "Belgian Strike Delays F100 Engines for F-16," *Aviation Week & Space Technology*, September 15, 1980, p. 25.

[51] Hymer (1980); "F-16 Engine Contract Terminated," *Aviation Week & Space Technology*, January 12, 1981, p. 21.

Avionics deliveries have not slowed aircraft deliveries, although delivery of some systems, such as the radar, have lagged behind delivery schedules, requiring out-of-station installation on aircraft assembly lines and delaying spares deliveries. These delays may adversely affect the supportability of the system early in its operational life.

Through February 1980, deliveries from three of the four major radar subcontractors in Europe lagged one to three months behind schedule, although only delays in radar computers were critical. The extreme compression of the radar development schedule and a considerable development effort to incorporate an air-to-ground capability in the radar has aggravated production problems for Westinghouse and its subcontractors on both sides of the Atlantic. Test problems on the European production line and difficulties in purchasing materials have also contributed to delays. The European contractor has responded by obtaining permission from its unions to add a second shift of test personnel. Westinghouse is building 80 additional computers at its Baltimore facility to guard against shortfalls from the European production line and has taken back some of the test responsibility from its European coproducer. As in the production of other parts of the weapon system, compensatory production in the United States has diminished possible adverse effects of European production difficulties.

Deployment. The first two U.S. site activations and the first site activation in each of the four European consortium countries have occurred on schedule. The schedule for deploying the F-16 to Hahn Air Force Base, Germany, has slipped at least six months because of factors unrelated to coproduction—shortages of F100 engines and the diversion of some production at General Dynamics to satisfy Egyptian and Israeli aircraft orders.[52] The Air Force achieved an initial operational capability at Hill Air Force Base 23 months after the initial operational delivery, which exceeds the 10 months required by the F-15 and 20 months required by the A-10. The U.S. force of F-16s is meeting or exceeding TAC planned aircraft utilization rates, TAC standards for mission capability status, and goals and standards for mission reliability. Maintainability, expressed in terms of maintenance man-hours per flying hour, is better than predicted. Hardware reliability, expressed in terms of mean time between maintenance actions, is meeting standards but is below predictions and goals.[53]

This performance has been achieved in spite of having to work under the handicap of an overall four-month slip in the Avionics Intermediate Shop schedule, including delays of up to eight months in the delivery of some AIS production units to the various bases. To compensate for the delays in the AIS program, the U.S. Air Force is using a combination of spares, workarounds (nonstandard maintenance procedures), and two years of interim contractor support (through 1980), including some contractor support at the base level. Similarly, European air forces are also relying on U.S. and European contractor support. The schedule for achieving an organic maintenance capability for other items not tested by the AIS has also suffered slippage of at least six months at the first USAF site.[54] Although the compression of the F-16 schedule and its concurrency has unquestionably created a particularly challenging management situation, we can observe that almost every new weapon system experiences initial support difficulties similar to those the F-16 is now having.

Observations. The political environment that spawned the F-16 coproduction program has required that the Air Force accept some scheduling risks to satisfy broader national

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[52] *Aviation Week & Space Technology*, May 26, 1980, p. 25.

[53] *Management Information Notebook*, November 30, 1980, pp. 55, 56, 60, 102, 104.

[54] *Management Information Notebook*, various issues.

policy objectives. Even so, as of December 1980, aircraft deliveries remained close to schedule, although keeping production lines on schedule may have some adverse effect on the operation and support posture of the system early in its operational life. One of the more encouraging aspects of the program thus far has been the reasonably flexible responses to adversity by key U.S. and European participants. For the most part, U.S. manufacturers have been able to support European coproducers when necessary to keep deliveries on schedule. In Europe, despite more restrictive work force policies, manufacturers have used multiple shifts, overtime, and temporary labor inputs to recover schedule slippage.

Future collaborative programs can profit from the F-16 experience, but we expect these programs will still have to deal with several of the same scheduling complications that have confronted F-16 program management. If there is some continuity between the F-16 program and subsequent programs, methods developed in the F-16 program to deal with differences in U.S. and European defense contracting procedures might reduce start-up delays, as could exploitation of newly modernized European facilities and working relationships between U.S. and European aerospace contractors. Workforce constraints and scale differences will still probably complicate the initiation of manufacturing activities, although European firms larger than those participating in the F-16 program may have somewhat more flexibility to transfer workers across programs to staff new projects rapidly.

Schedule complexities caused by differences in U.S. and European manufacturing times and lead times may persist, although some relaxation of European workforce constraints and the use of similar manufacturing techniques may contribute to narrowing the differences.

The international ramifications of making wholesale changes in program schedules will probably continue to confer upon future collaborative programs some measure of immunity from the persistent schedule changes that typify U.S. domestic programs.[55]

Whether complexities caused by scheduling fabrication and assembly operations at multiple locations will recur in future programs will depend on how much U.S. decisionmakers insist on maintaining a complete indigenous production capability, the performance of European contractors in meeting schedules, and the extent to which the F-16 program experience displays the advantages of the multiple fabrication and assembly arrangement. Clearly, the F-16 program has demonstrated thus far that there are differences in a purely European collaboration and collaboration in which the U.S. participates. The scale of production possible in the United States, the flexibility of labor inputs possible by U.S. industry, and the duplication of production and assembly operations have thus far allowed the F-16 program to avoid the long delays that have characterized a number of purely European collaborative efforts.

COST IMPLICATIONS[56]

Every aircraft is coproduced in the sense that a prime contractor procures assemblies, subassemblies, and components (wings, fuselage sections, avionics, etc.) from other contractors and suppliers and integrates them into a finished system. The practice is efficient and effective. However, multinational military programs are likely to introduce inefficiencies

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[55]Dews et al. (1979), pp. 71-76.

[56]Allen A. Barbour contributed material used in the preparation of this subsection.

that will increase the total cost of the program, including duplication of production and assembly responsibilities and mandated subcontracting in certain geographic areas.

Undertaking the same production work at several different plants can result in substantial losses of economies of scale, which can in turn increase labor, overhead, and material costs. For example, in the current F-16 program, Fokker and SONACA/SABCA perform the final assembly of 174 aircraft apiece, while General Dynamics assembles an additional 650 units. Theoretically, this could increase total manufacturing hours by about 50 percent.[57] Further, requiring a prime contractor to place a specified dollar volume of business in certain geographic areas—whether a European nation or an individual state—reduces the likelihood of finding and selecting lowest-cost qualified suppliers.

The additional cost caused by these and other factors introduced by national differences is accepted by many in the U.S. defense community as part of the price of greater standardization of NATO equipment and by many Europeans as the price of various domestic economic and industrial development goals. This acceptance is rarely predicated on a detailed analysis of the incremental costs and benefits of collaborative production, however. The F-16 program provides an excellent opportunity to conduct such an analysis. This section examines the cost implications of the coproduction arrangements from perspectives of the United States and the European participating governments. Below we look at the competitiveness of participating European and U.S. manufacturers.

Effects on Current U.S. Program Cost

Coproduction is expected to increase the cost to the U.S. Air Force of its first 650 F-16s by an amount equal to about 5 percent of the total Air Force program cost. Exchange rate fluctuations are expected to add about $40 million to the estimated totals shown in Table 22.

This net effect of the coproduction arrangements is a product of two factors. First, the sale of F-16s to the EPG (and production of 60 percent of their procurement value) has increased the production volumes of most participating U.S. contractors. This has reduced certain components of the cost incurred by the U.S. Air Force. For example, when all assemblies produced by General Dynamics for EPG aircraft—348 forward fuselages, horizontal stabilizers, etc.—are added to production at Ft. Worth for USAF aircraft, and all assemblies manufactured in Europe and shipped to Ft. Worth for USAF aircraft are subtracted, the net result is an equivalent Ft. Worth production run of approximately 794 units. Spacing 650 Air Force units over a 794-unit production run results in a labor cost savings: Manufacturing hours at the 794th unit are about 7 percent lower than at the 650th unit. Materials cost savings occur as well, though the effects are less pronounced. General Dynamics overhead cost, a function of direct labor and material cost, declines most of all (see Table 23).

Second, incorporation of European-produced items, in lieu of American-produced items, has increased the total cost of subcontracts in the program. Some reasons for higher EPG

[57]This assumes that the hours required to manufacture the first unit are the same at each plant and that each plant follows a 75 percent learning curve. In practice, however, the second and third contractors to begin production usually require fewer hours than the initial contractor to turn out their first units because they can often exploit the learning that has already occurred. But subsequent producers often have flatter learning curves.

Table 22

ESTIMATED EFFECT OF COPRODUCTION ON THE COST OF THE FIRST 650 USAF F-16s

Aircraft Group	Estimate 1	Estimate 2
Airframe[a]	+37.6	+79.0
Engine	+76.3	+93.1
Other GFAE	+ 6.4	+17.9
Initial spares	+21.7	—
	+$142.0	+$190.0

SOURCES: Estimate 1 — Peat, Marwick, Mitchell and Company, *F-16 Multinational Coproduction Impact Analysis*, 1977; Estimate 2 — U.S. Air Force, Air Force Systems Command, Aeronautical Systems Division, *F-16 Independent Cost Analysis*, October 1977, unpublished.

[a]Includes avionics.

Table 23

ESTIMATED EFFECT OF COPRODUCTION ON THE COST OF THE FIRST 650 USAF F-16 AIRFRAMES[a]

Cost Category	Estimate 1	Estimate 2
Labor	− 58.3	− 33.3
Materials	− 3.3	− 13.0
Subcontracts[b]	+207.1	+195.7
Overhead	−125.7	− 78.3
Other	+ 17.8	+ 7.9
	+$ 37.6	+$ 79.0

SOURCES: Estimate 1 — Peat, Marwick, Mitchell and Company, *F-16 Multinational Coproduction Impact Analysis*, 1977. Estimate 2 — U.S. Air Force, Air Force Systems Command, Aeronautical Systems Division, *F-16 Independent Cost Analysis*, October 1977, unpublished.

[a]Avionics included. Negative values represent economic benefits.

[b]This includes the subcontractors' direct labor and overhead costs, as well as costs of material not supplied by prime contractors.

prices are clear: For example, they include the cost of the technology transfer and an administrative charge (called a loading). Other explanations are less obvious. For instance, several smaller European manufacturers have reported that the administrative burdens of U.S. procurement regulations have increased their costs by as much as 30 percent.[58] Some reasons for U.S.-European price differentials are discussed in more detail below.

The magnitude of U.S.-European price differences varies across major sections of the aircraft. The following discussion examines the airframe, avionics suite, and the engine. It draws primarily from a data base maintained by the F-16 System Program Office[59] augmented by Rand visits and discussions with major contractors and subcontractors in the United States and Europe. The analysis examines average unit prices for part sets[60] that are manufactured or assembled (or both) at both U.S. and European facilities.[61]

Airframe and Avionics. Figure 33 illustrates the premium being paid by the U.S. Air Force for coproduced airframe and avionics part sets. The basic comparison is identical to that of Tables 22 and 23: Are USAF costs under the present arrangement higher or lower than they would have been had U.S. contractors exclusively produced the 650 aircraft? For over two-thirds of the part sets analyzed, the answer is higher.[62] The price differential is not often large; in only a quarter of the cases is it more than 30 percent. Moreover, our results indicate that eight part sets (most of them related to the airframe) would be more expensive in an all-U.S. production program, although none of them is very costly. In fact, 12 of the 13 highest-priced items analyzed are more expensive when coproduced, which explains why on balance coproduction is expected to increase the cost of airframes and avionics to the Air Force (as shown in Tables 22 and 23).

Engine. The coproduction arrangements have increased F100 engine costs more than costs of any other part of the aircraft (see Table 22). It is not surprising that U.S.-European price differentials are greatest for engine parts; when F-16 production began, Pratt & Whit-

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[58]One example frequently cited is U.S. quality control procedures, which are more detailed and more formalized than European procedures to which the coproducers are more accustomed.

[59]The data—based on negotiated firm, fixed-price contracts—were collected during late 1978 and the first half of 1979. The prices were based on planned production rates of 15 aircraft per month at General Dynamics and three per month at both Fokker and SONACA/SABCA. They include certain tooling costs, other nonrecurring costs, technical coordination of European production efforts, resident offices in Europe, recurring factory and engineering costs directly related to hardware production and checkout, system engineering and management, all related indirect and general and administrative costs, as well as an assumed rate of profit. U.S. subcontractor loadings are applied to appropriate European second-tier subcontractor prices. Finally, USAF and EPG units are uniformly distributed within the production plan of each manufacturer.

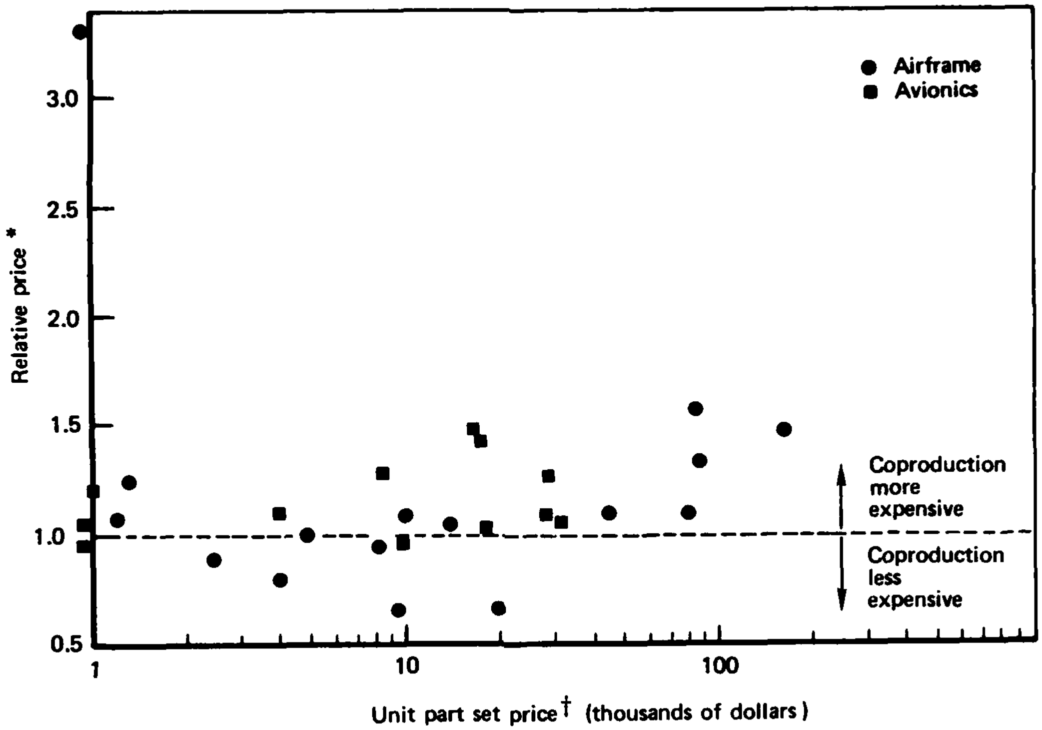
Negotiated prices do not always reflect underlying costs. Some EPG contractors (especially those lacking significant aerospace experience) have had to hire temporary workers and use overtime and extra shifts at premium rates. Furthermore, EPG prices probably do not fully reflect the substantial necessary capital investment, some of which was provided by the governments. U.S. contractor prices may not reflect true costs, either; artificially low bidding is often done in anticipation of follow-on buys or in order to expand the firm's business base.

[60]A part set is a system, subsystem, assembly, or component that is manufactured, assembled, or tested. By this definition, the airframe final assembly, wing assembly, nose landing gear, engine gear box, and fire control radar are all part sets.

[61]The data base divides the entire system into 132 part sets, of which about 62 percent are coproduced. (Not all are amenable to analysis.) One part set is the responsibility of three facilities (integration and assembly of the airframe occurs at General Dynamics, Fokker, and SONACA/SABCA); the rest are each manufactured or assembled at one U.S. facility and one European facility (except for HUD production in the United Kingdom instead of in the United States).

[62]Of the 53 coproduced airframe and avionics part sets, 30 (about 57 percent) were analyzed. The primary reason for excluding some part sets was uncertainty about how to treat "European end items" that contained U.S.-supplied parts or materials. For example, Northrop produces and furnishes 95 percent of the component parts for Kongsberg's production of the rate gyro. The subset chosen for analysis represents about 89 percent of the total procurement value of the 26 coproduced airframe part sets and 37 percent of the total procurement value of the 27 coproduced avionics part sets.

To protect proprietary and otherwise sensitive financial data, we do not identify individual part sets or contractors.



*Ratio of average price to USAF, current 998 aircraft coproduction program, to average price to USAF, hypothetical all-domestic 650 aircraft program. Value greater than 1.0 denotes part set that is more expensive when coproduced.

†Average price to USAF, hypothetical all-domestic program (1975 dollars)

Fig. 33—Estimated effect of coproduction on the cost to the USAF of selected airframe and avionics part sets

ney had produced nearly 1000 F100 engines for the F-15, giving it a significant experience edge over its F-16 European subcontractors.[63]

Comparing U.S. and European prices at the individual part set level proved impossible. EPG engine part sets generally consist of a mixture of European-produced parts and U.S.-supplied materials, semi-finished parts, and finished parts. (Some engine parts are produced only in the United States.) For example, the engine gearbox consists of about 150 parts. DISA, the original EPG gearbox supplier, was to fabricate 49 of the parts from materials supplied by Pratt & Whitney and assemble the gearbox with 101 additional Pratt & Whitney-supplied parts.[64]

External Benefits. Limiting the search for costs and benefits of the coproduction ar-

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[63]Because F100 production for the F-15 has continued concurrently with F-16 production, Pratt & Whitney continues to experience large economies of scale. The benefits accruing to the F-15 program are discussed below.

[64]Many materials and parts were furnished at reduced prices to minimize loadings (which in the case of the engine are a fixed percentage of the EPG base price).

rangements to the F-16 program per se would be misleading. Such a narrow focus excludes various unquantifiable benefits, such as increased NATO standardization, as well as significant tangible benefits that can be estimated. A prominent example is the fee paid by the EPG (as part of the NTE price) for recoupment of R&D costs. This fee, totaling $163.56 million (1975 dollars), is paid directly to the U.S. Treasury.

The expanded business bases of the principal U.S. contractors theoretically permit reductions in the overhead rates[65] charged to all programs within plants involved in F-16 production. Estimates of the resulting savings in Pratt & Whitney's F-15 F100 program and General Dynamics' F-111 spares program over the next six years are about $50 million (1975 dollars).[66] These expanded business bases also generate additional tax revenues, although estimates of their magnitude would be speculative.

Effect on U.S. Follow-on Buys

The U.S. Air Force is currently contemplating the purchase of 738 additional F-16s. Inasmuch as there is no formal commitment to the EPG for European participation in the production of USAF aircraft beyond the 650th unit, we compared the costs of 738 additional F-16s *with* and *without* European production participation.[67] The results are shown in Table 24. Coproduction could potrntially add about 8 percent to the total cost of the follow-on program, although the prices of coproduced part sets could vary substantially depending on the extent of European production and whether the practice of loadings was continued (see Fig. 34).

Table 24

ESTIMATED COST OF A FOLLOW-ON BUY OF 738 F-16S, WITH AND WITHOUT COPRODUCTION
(Millions of 1975 dollars)

	Estimated Total Cost to USAF of Follow-on Buy	Estimated Average Cost to USAF Per Aircraft
With coproduction	2,863	3.9
Without coproduction	2,619	3.6

A policy that would permit selective European participation based on price considerations might benefit the Air Force. As Fig. 35 shows, EPG contractors could produce several moderate priced airframe part sets less expensively than U.S. contractors because of substantial quantity differences—for some items, almost 7:1—in the original program. This situation

[65]Overhead rate is defined as total overhead cost divided by total direct labor cost. Materials cost is not included.
[66]Peat, Marwick, Mitchell, and Company (1977).
[67]For the hypothetical case of 738 additional F-16s produced with European participation, we assumed for analytic purposes (1) an aggregate 10 percent share for the EPG, (2) European production of the same parts in the same proportion as in the initial buy, (3) no additional European or other foreign purchases, and, most important, (4) no renegotiation of the contract terms that now comprise the data base.

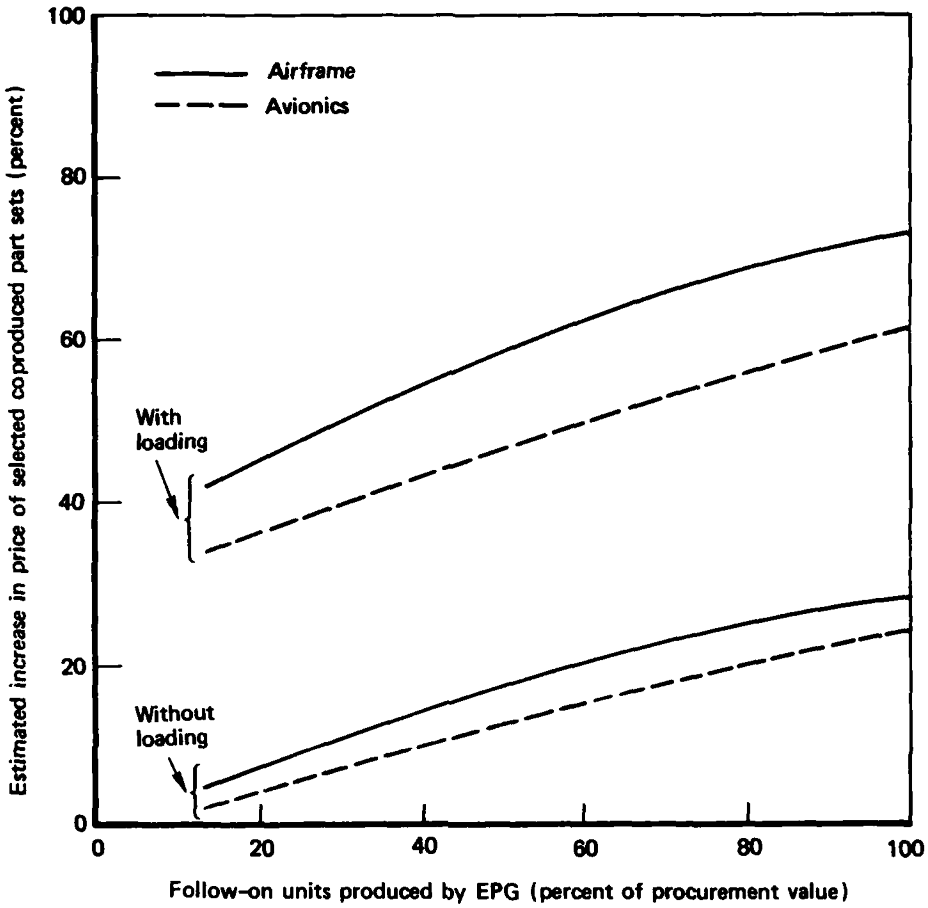
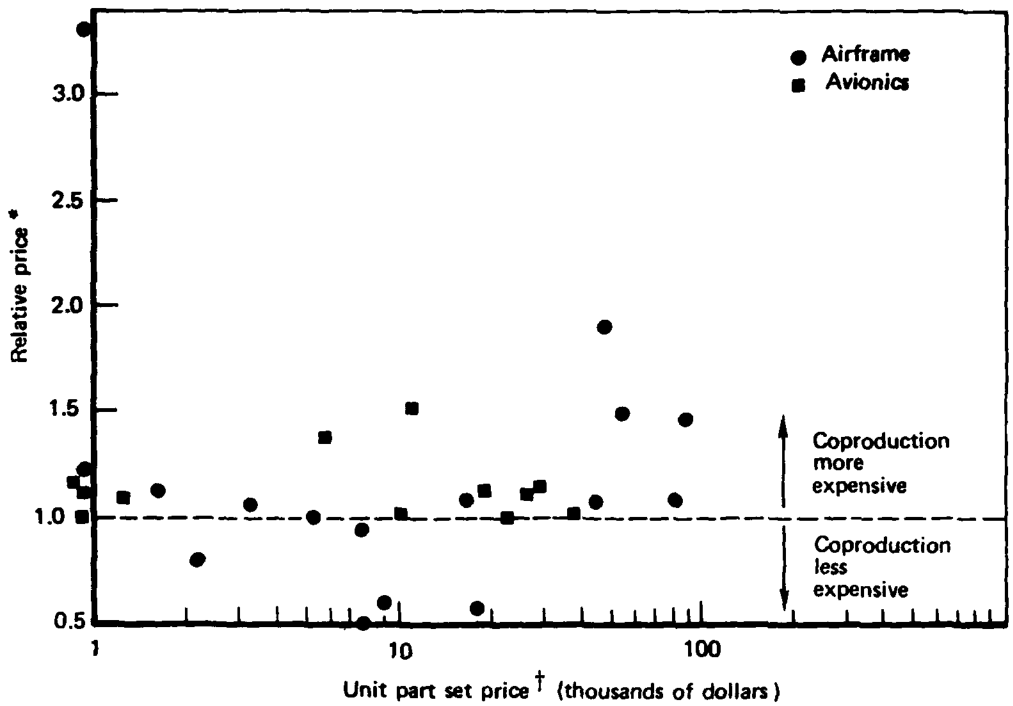


Fig. 34—Estimated increase in price as a function of EPG participation in a follow-on program

contrasts with that for avionics. It is unlikely that General Dynamics would experience any cost penalty if it relied exclusively on U.S. contractors for avionics in a follow-on program.

When one considers a follow-on Air Force buy, it is important not to overlook the effect of the initial coproduction program, even if further European production participation is not contemplated. Recall that domestic production was generally greater because of the EPG purchases. The resulting economies of scale (which were slightly more than offset by incorporation of European-produced items in the first 650 aircraft) would have a measurable effect on the cost of domestically produced follow-on aircraft. Specifically, 738 follow-on aircraft produced entirely by U.S. contractors would cost over $100 million more (1975 dollars) had there been no previous U.S. production for the EPG.[68]

[68] F-16 Independent Cost Analysis (1977).



*Ratio of average price to USAF, follow-on program with coproduction, to average price to USAF, follow-on program without coproduction.

†Average price to USAF, hypothetical all-domestic follow-on program (738 aircraft, 1975 dollars)

Fig. 35—Estimated effect of follow-on coproduction on the cost of selected airframe and avionics part sets

Effect on EPG Program Cost

By choosing coproduction as the best way to use and develop industrial, technical, and economic resources, the EPG bypassed several alternative acquisition options. Discussion with various European government officials indicated it was widely believed that F-16 coproduction (as opposed to a direct purchase) would increase the EPG's program cost; estimates of that increase ranged from 10 to 30 percent.[69] In the discussion that follows we examine this assumption and some of the quantifiable and nonquantifiable benefits experienced by the EPG and its participating contractors.

Selected EPG Acquisition Options. Table 25 lists four options involving direct EPG purchases of 348 F-16s from General Dynamics.[70] Two postulate average cost pricing, one for a total production run of 998 aircraft, another for a run of 1736 aircraft. The other two postulate block purchases at the beginning and at the end of a 998-aircraft production run.

[69]These perceptions were formed before contracts were signed.
[70]The influence of "third-country" sales is ignored.

Table 25

ESTIMATED COST SAVINGS FROM ALTERNATIVE EUROPEAN DIRECT PURCHASE OPTIONS

	Option	Estimated Savings Relative to Actual Arrangement (Percent)
I.	Purchase first 348 aircraft from General Dynamics line	19
II.	Purchase 348 (assume average cost of 998 aircraft produced)	34
III.	Purchase 348 (assume average cost of 1736 aircraft produced)	43
IV.	Purchase last 348 aircraft from General Dynamics line (assume 998 produced)	44

Option I would have delayed U.S. deliveries too long, Option IV would have delayed EPG deliveries too long, and Option III would have probably stretched EPG deliveries over too long a period; each therefore probably would not have been practical. By selecting the current coproduction arrangement over Option II (a direct buy from General Dynamics), the EPG appears to have accepted a 34 percent cost penalty.[71]

Another way of viewing Option II is to compare the price of part sets currently produced by the Europeans and incorporated in EPG aircraft with the estimated price of those part sets had U.S. contractors produced them all (see Fig. 36). With the exception of the least expensive airframe part sets, the premium paid for these parts is substantial.

Achieved Offsets and Other Benefits. Whatever the actual size of the "premium" paid, it must be viewed together with the economic value of the coproduction opportunity and the potential long-term benefits.

The offset commitment in the F-16 program is for a *percentage* of total procurement value rather than a fixed or semi-fixed dollar target. The offset formula is:

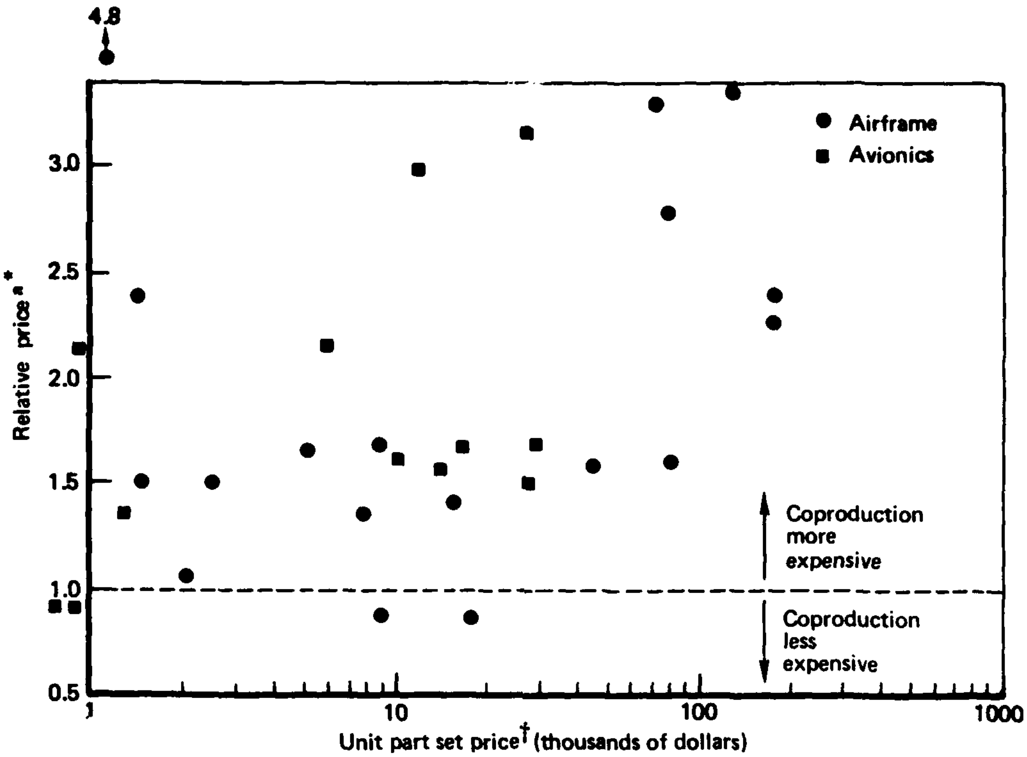
$$\frac{\text{Value of Work Contracted to EPG Industry}}{\text{Procurement Value of the 348 EPG F-16s}} \times 100 = 58\%$$

Changes in the procurement value[72] of the F-16 baseline configured aircraft could result in changes in the required offset, but this has not yet occurred.

In 1975 the Air Force and its prime contractors seemed confident of their ability to achieve the 58 percent offset goal. However, inability to find enough firms in each nation that

[71]This conclusion does not apply to any contemplated EPG purchases beyond 348 aircraft.

[72]Procurement value as used in the MOU includes the following costs: flyaway cost, aerospace ground equipment, technical orders, manuals, training equipment, initial spares, and a pro rata share of nonrecurring development costs.



* Ratio of average price to EPG, current coproduction program, to average price, hypothetical all-U.S. production program (998 aircraft).

† Average price to USAF, hypothetical all-U.S. production program (998 aircraft, 1975 dollars).

Fig. 36—Estimated effect of coproduction on the cost to the EPG of selected airframe and avionics part sets

have the necessary industrial capability to produce subsystem parts at "reasonably competitive" prices has left the program short of that goal. Currently, an overall offset value of nearly 52 percent has been achieved with the EPG countries. This leaves about 6 percent of the value to be placed to bring the program to the full agreed value (see Fig. 37).

The offset percentage is a commitment to EPG countries as a group and does not address significant differences in aerospace industrial capacity and capability among the four EPG participants.[73] Belgium and Holland, which have the largest numbers of aircraft on order, have an industrial infrastructure capable of carrying out major, high-value tasks, including final assembly of aircraft. Although The Netherlands' offset has reached a bit more than 50 percent, Belgium is well over the 70 percent mark. In Denmark and Norway, with no

[73] Although the offset commitment is to all four European countries as a whole, the United States has agreed in the MOU to the principle of prorating the coproduction work among the four nations based on the number of aircraft purchased by each.

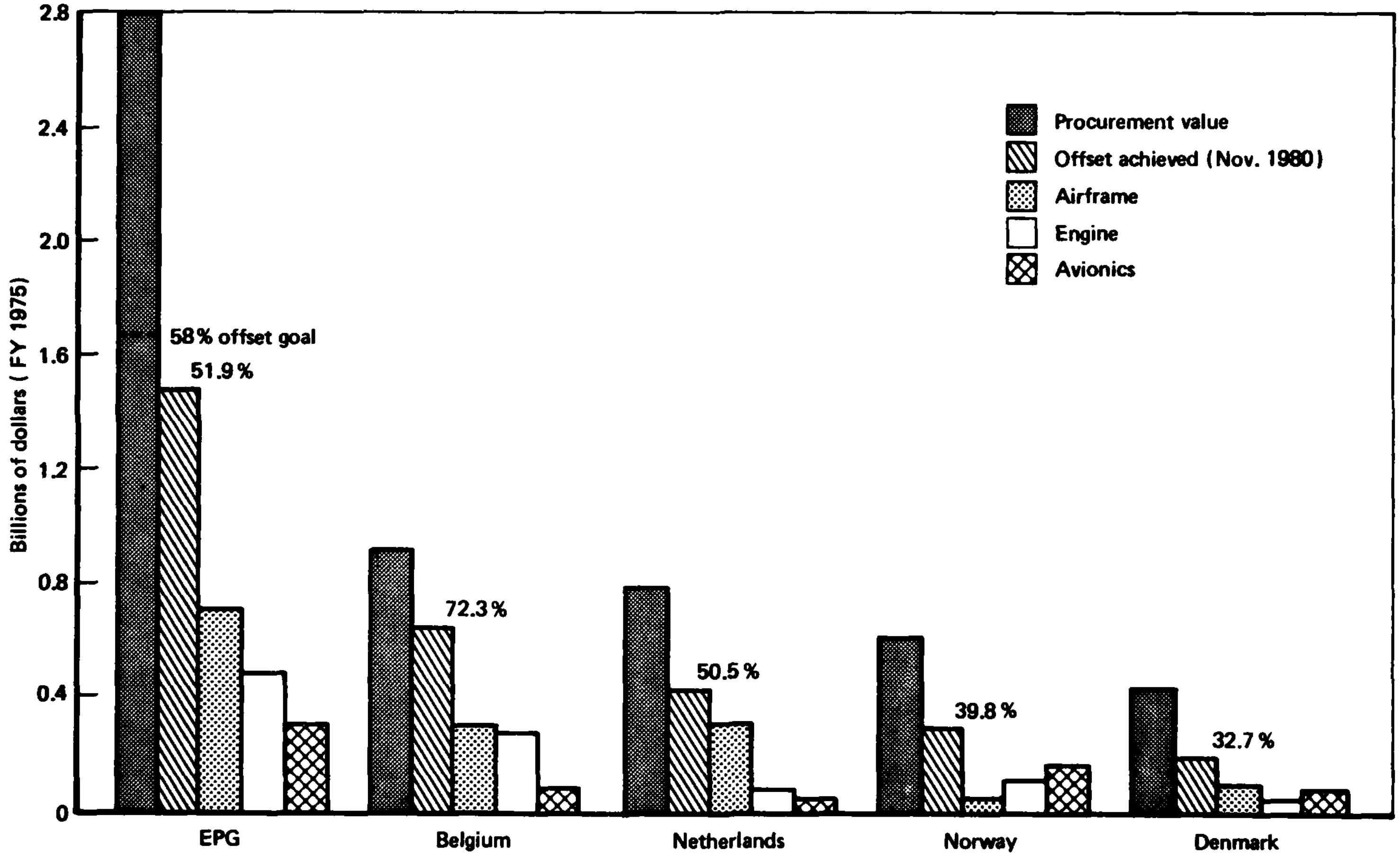


Fig. 37—Distribution of EPG procurement and offset by country

indigenous aircraft industry, placing work has been more difficult: As of early 1981, Denmark had only a 33 percent offset and Norway's was slightly more than 40 percent. Although the U.S. government has until 1985 to satisfy the overall commitment to the consortium, redressing this uneven distribution will continue to be troublesome. The SPO is attempting to achieve a more equitable balance by placing additional contracts for mission equipment, spare parts, additional F100 engine work, and electronic warfare training devices, and hopes that third country sales will help.[74]

As a result of such difficulties as these, the Secretary of Defense has issued new guidelines governing offset agreements. The policy now calls for DoD and the services to enter into offset agreements only when there is no other way of successfully negotiating a transaction of significant importance to national security interests. In addition, when offset and compensatory coproduction agreements are found to be necessary, they are to be as flexible as possible, specific offset targets are to be avoided, and the burden for fulfilling the commitments is to rest with the U.S. contractors involved in the program, rather than with the government.[75] If these policies are adhered to, they should help in avoiding many of the difficulties encountered in the F-16 program.

The work placed in the EPG industries has important benefits beyond the F-16 coproduction program. The new skills, invested capital, modern technology, and management discipline introduced by this program are significant by-products. An example of a beneficiary is DAF of The Netherlands, which produces both the nose and main landing gears. Well known for its trucks, DAF had no aerospace experience before the F-16 program. However, it built and equipped an entirely new factory, investing nearly $9 million. As a result, DAF will be able to compete for new landing gear contracts for years to come.

A comprehensive, realistic evaluation of F-16 coproduction from the EPG perspective must consider more than the incremental program cost due to the collaborative arrangements. A broader view encompasses significant current and future benefits (including prospective shares of export markets and U.S. follow-on buys).

EPG Price Competitiveness

It would be a serious error to draw any conclusions from the analysis so far about the actual price competitiveness of participating EPG contractors. Up to now, the average U.S. and European unit price comparisons have not been adjusted for differences in quantities produced or the loadings on EPG products. However, this adjustment will now be made.

Quantity Differences. In the aerospace industry costs are expected to decrease on each successive part. If all other factors are equal, the producer who manufactures greater quantities of a given item should have the lowest average unit costs. Thus, quantity differences can play an important role in determining which producers are most competitive. For all coproduced airframe, engine, and avionics part sets, the EPG's share of production runs is shown in Fig. 38. For coproduced part sets, EPG firms produce from 22 to 97 percent of the total production quantities. The engine distribution is unusual—bimodal—with EPG firms usually

[74]The MOU requires fulfillment of the offset through coproduction efforts on the F-16 aircraft. If it becomes impossible to achieve the offset through F-16 coproduction, a provision is included to achieve the offset through "compensatory work of comparable technology."

[75]Secretary of Defense Multi-addressee Memorandum, "General Policy on Compensatory Coproduction and Offset Agreements with Other Nations," May 4, 1978. This Memorandum is Enclosure 4 of DoD Directive 2010.6, "Standardization and Interoperability of Weapon Systems and Equipment within the North Atlantic Treaty Organization," 5 March 1980.

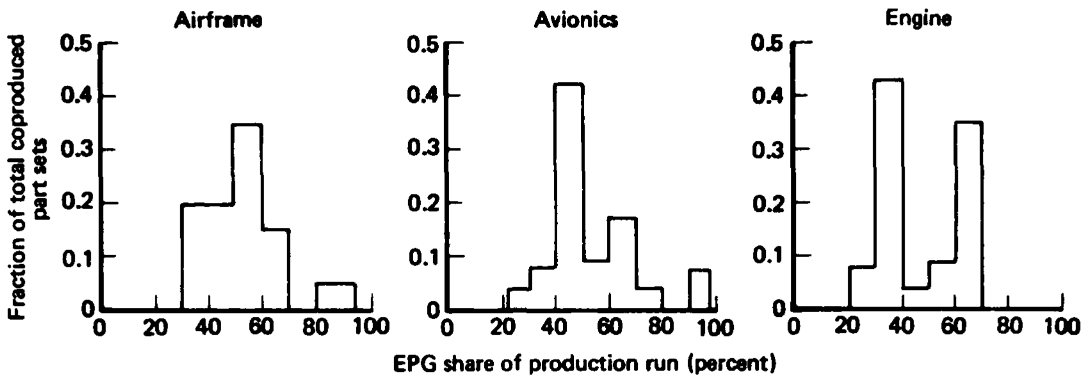


Fig. 38—EPG share of entire part set production runs by aircraft group

producing either one-third or two-thirds of the part sets. These data suggest that during original production planning, care was taken to ensure that most EPG firms received economical production runs. Original plans had EPG firms producing the larger share of 43 of the 82 coproduced part sets. Figure 39 shows a breakdown by EPG country.

Loadings. U.S. contractors charge their customers for the management, administration, and support effort needed to assure quality control and on-time delivery of end items produced by their subcontractors. That charge is generally referred to as a "loading" or "load." How a loading is applied depends on a firm's overhead structure; loadings usually include such costs as material overhead, general and administrative expenses, and profit. Typically, a first-tier subcontractor receives an item from a second-tier subcontractor. After performing inspections and perhaps quality control testing, the part is packaged and forwarded to the prime contractor; the price paid by the prime contractor includes the loading, which is determined by applying a rate or fixed factor to each of the services covered.[76] Similarly, the prime also adds a loading when the item is delivered. This method has evolved as the most efficient and economical way for U.S. corporations to recover these costs. It avoids the difficulty and expense of making more precise allocations. The cumulative effect of loadings when a program is fragmented with many first- and second-tier subcontractors can greatly increase costs.

Loadings applied to European-manufactured part sets by U.S. contractors are appreciable (Table 26). European second-tier subcontractors in the F-16 program have complained about this practice because it puts them at a disadvantage in competing with U.S. first-tier subcontractors. For example, Menasco, a U.S. company, and DAF of The Netherlands both manufacture landing gear for the F-16, but Menasco is a subcontractor to General Dynamics, and DAF is a subcontractor to Menasco. General Dynamics prefers that arrangement because it places design, development, and production responsibility for the DAF landing gear on Menasco. However, the DAF product will be more costly to General Dynamics even though actual production costs may be comparable.

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[76]European firms usually follow the practice of relating loadings to actual values by direct costing, with similar items having the same loadings applied.

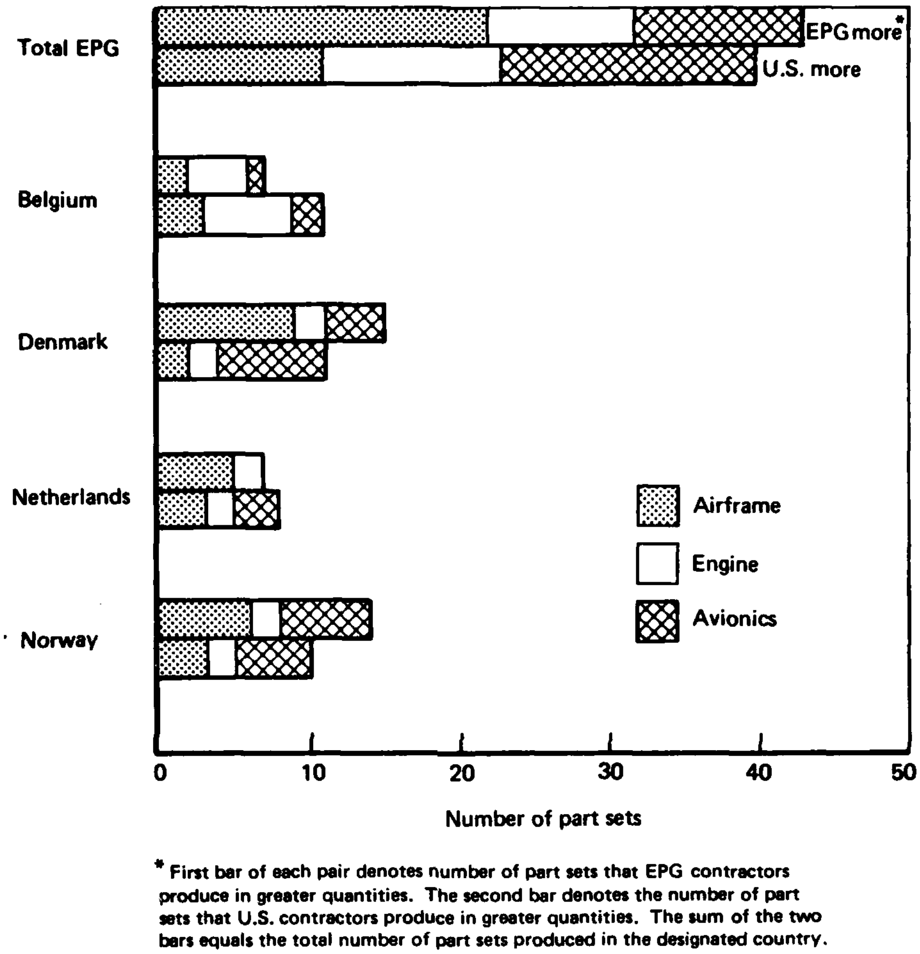


Fig. 39—A comparison of production quantities of coproduced part sets

Adjusted Price Comparisons. Relying on price-quantity relationships contained in the F-16 SPO data base, we compared U.S. and European price differentials for airframe and avionics part sets when effects of loadings and quantity differences are removed. Competitiveness is measured in terms of cumulative average unit prices for production quantities of 500 units. Because the decision not to coproduce certain part sets was undoubtedly predicated on the fact that EPG contractors either did not have the required technical capability or were not price competitive, this analysis may portray the competitiveness of EPG contractors in a more favorable light than if we were able to measure competitiveness across all part sets that make up the weapon system.[77]

[77]EPG contractors also benefit in this comparison from the previous learning of U.S. contractors, which is theoretically passed on in the technology transfer process. Even these adjustments cannot ensure a totally fair

Table 26

SUMMARY OF LOADINGS

Aircraft Group	Average Loading	Range
Airframe	1.36	1.00[a] - 1.67
Engine	1.36	1.11 - 1.55
Avionics	1.29	1.10 - 1.42
Overall	1.34	1.00[a] - 1.67

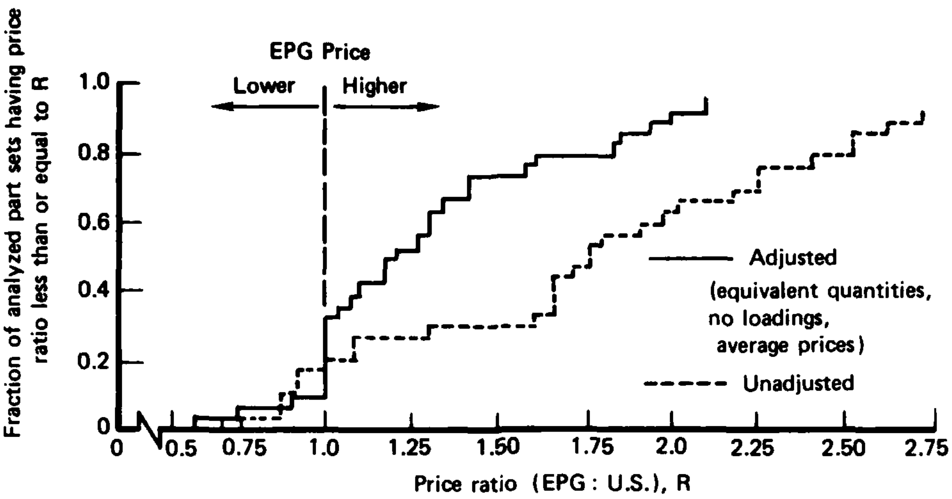
[a]In one instance, a U.S. company applied no lo ding to its European division.

Adjusting for quantity differences and loadings of airframe and avionics part sets results in a pronounced increase in EPG contractor price competitiveness (see Fig. 40(a)). Even with this major adjustment, EPG prices in this hypothetical case are still only competitive with U.S. prices (having price ratios less than or equal to 1.0) for about one-third of the airframe and avionics part sets in the sample (see Fig. 40(b)). Moreover, those part sets that EPG contractors can produce competitively tend to be among the least costly items in the sample. Airframe part sets that EPG contractors can produce competitively are on average only about one-tenth the price of those they cannot produce competitively. The disparity is not so great for the avionics part sets in the sample: Competitively produced part sets are on average about three-fourths the price of part sets for which EPG contractors are not competitive. In general, the large group of more expensive part sets that EPG contractors cannot produce competitively dominates the smaller group of low-priced part sets that they can produce competitively.

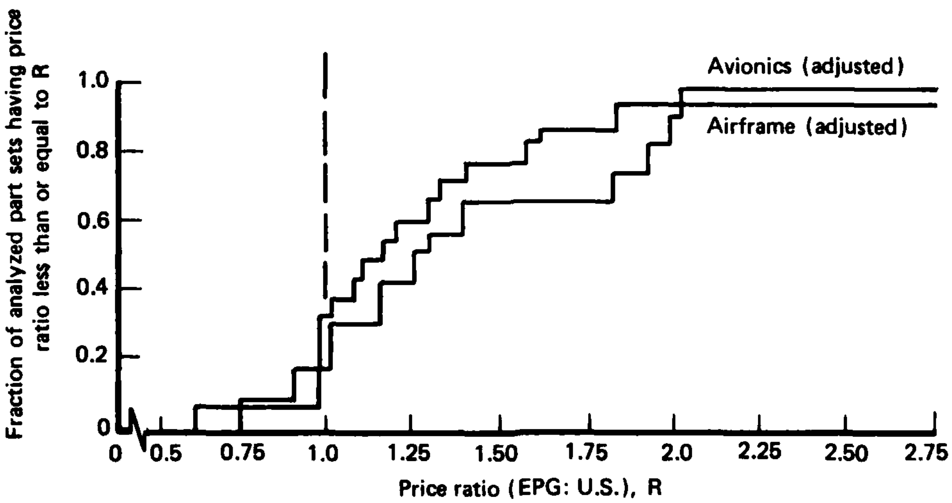
Clearly, the difficulties that EPG contractors have in competing with U.S. contractors derive from more than just the effects of loadings and quantity differences. Viewed from the U.S. perspective, the prices of European-produced items are determined by many factors, including currency exchange rates and relative inflation rates. Figure 41 presents adjusted economy-wide price indexes suggesting that when both exchange rates and inflation are taken into account, European prices rose faster than U.S. prices through the 1970s. The picture is similar in the particular industry of interest to this study: In general, inflation in aerospace products and production factor prices has exceeded overall consumer and wholesale product price growth in both the United States and Europe.[78] If it continues, the trend of increasing European prices will make avoiding substantial cost penalties when subcontracting with European nations—especially ones similar to those constituting the EPG consortium—a considerable challenge in future collaborative endeavors.

comparison, however. In the F-16 program the EPG firms are producing American designs that were optimized for American production methods, available machinery, tools, plant layouts, and worker skill levels. Moreover, adjustments for production rate differences cannot be made with precision.

[78]See Appendix B.

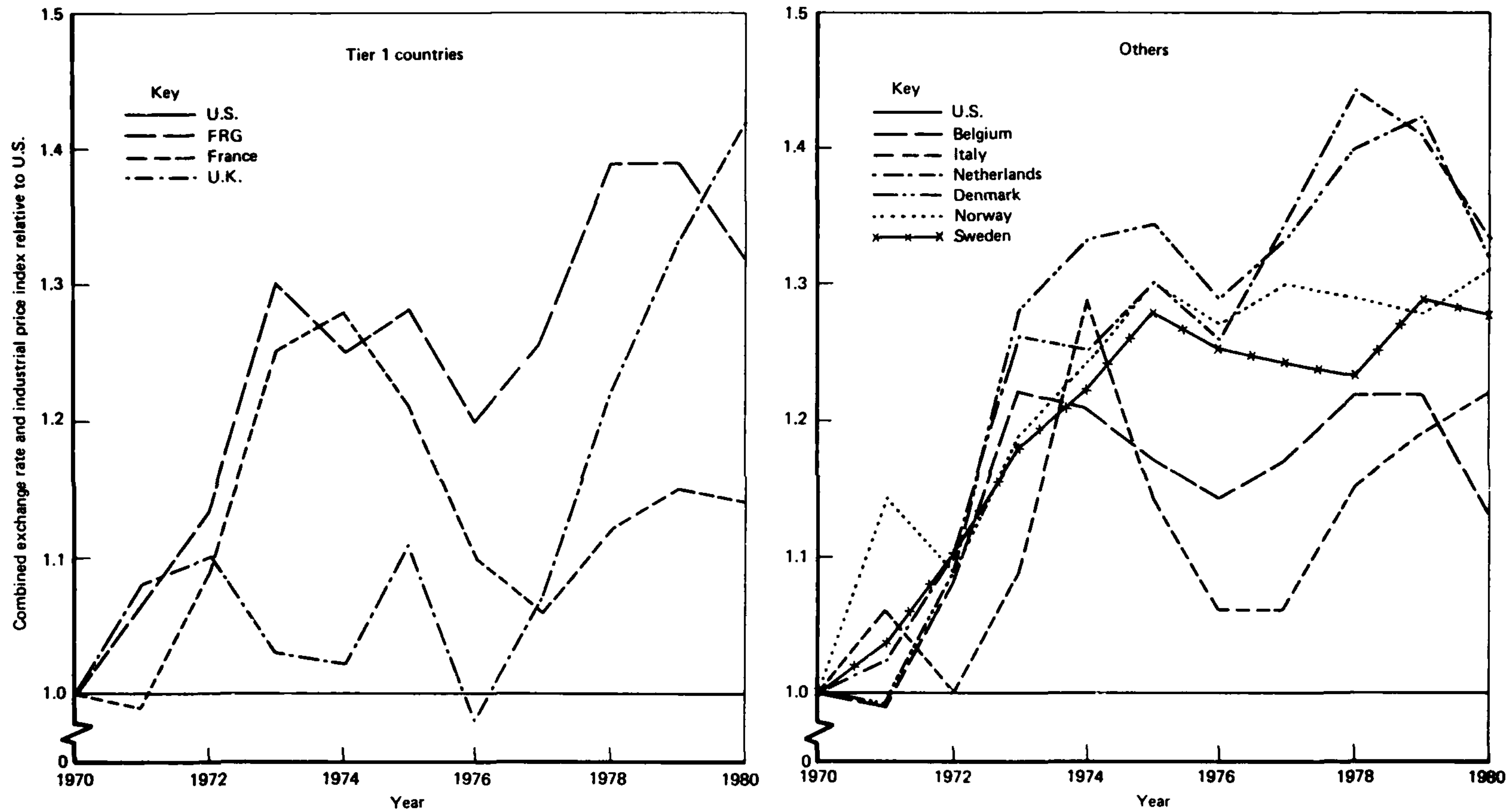


(a) Effect of loadings and quantity differences



(b) Comparison of adjusted prices by part set type

Fig. 40—Relative price competitiveness of U.S. and EPG contractors, selected airframe and avionics part sets



SOURCE: OECD Economic Outlook Reports; International Financial Statistics, Country Tables, Line 63.

Fig. 41—Trends in European industrial prices relative to U.S. industrial prices (adjusted for exchange rate and domestic industrial prices, January 1970 = 1.00)

Cost History to Date

By the fall of 1980, the U.S. F-16 program had experienced some cost growth, but far less than most other major programs at the same stage. Growth during the FSD phase was approximately 28 percent, owing principally to the addition of a radar warning receiver, some minor engine reliability improvements, and underestimation of support costs (see Table 27). Costs rose less rapidly during the production phase; total program cost growth has been about 15 percent. This record compares very favorably with other acquisitions of the 1970s (see Fig. 42). There can be little doubt that the stability promoted by the program's multinational character is a factor in this outcome, as reflected by the absence of cost growth due to schedule changes (see Fig. 43).

Table 27

ESTIMATED COST GROWTH IN THE U.S. F-16 PROGRAM

		Baseline Cost Estimate[a]	Estimated Cost Growth[b]	
Phase	Aircraft Quantity	(Millions of 1975 Dollars)	(Millions of 1975 Dollars)	Percent
Development	8	578.6	165.4	28.3
Procurement	650	3,798.2	505.1	13.3
Total program	658	4,376.8	670.5	15.3

[a]Made at start of full-scale development (DSARC II).

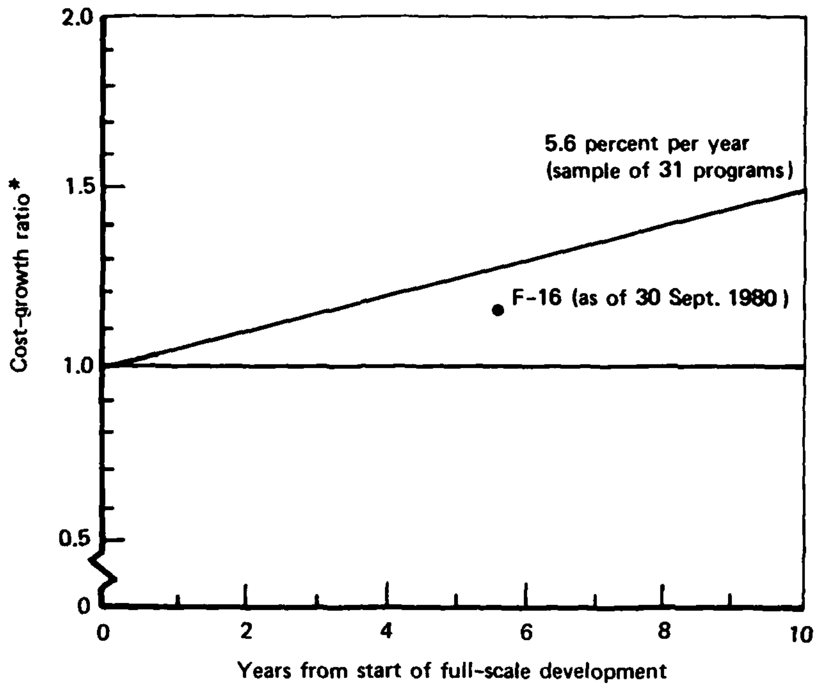
[b]F-16 Selected Acquisition Report, 30 September 1980. Values shown were normalized to originally planned quantities.

CONCLUDING OBSERVATIONS

Slightly more than five years after the United States and the European consortium signed the MOU setting forth the basic principles governing the F-16 coproduction program, nearly 300 aircraft had been delivered from three final assembly lines. Production rates approached their maximum planned values in Europe and the United States. Seven nations had purchased F-16s, and aircraft were deployed in the United States, Europe, and Israel. Although it will be some years before we can fully assess schedule and cost implications of the F-16 coproduction arrangement, the experience accumulated thus far permits some preliminary observations.

Schedule Implications

- Decisions reached at the political level by the United States and its European collaborators have preempted some Air Force scheduling options and have had a considerable effect on the program schedule.



* Ratio of current program cost estimate (various dates) to estimate made at start of full-scale development.

NOTE:
Data adjusted to eliminate the effects of inflation and quantity changes.

Fig. 42—Cost growth of F-16 relative to 1970s programs

These decisions, reflecting efforts to satisfy a broad set of political, military, and social goals in five countries, transcend the Air Force and its operational mission and introduced more schedule complexities and program risks than there might have been in a purely domestic program. The Air Force may find itself operating in similar environments in the future and there is no guarantee that such international agreements, negotiated to satisfy disparate goals, will permit the Air Force to adopt prudent scheduling directed toward best satisfying its own goals.

- The ambitious delivery schedule may have an adverse effect on the support posture of the F-16 early in its operational life.

Meeting the early delivery dates specified by the European governments contributed to the sale of the F-16 but also effectively foreclosed the sequential development and production of some key subsystems. This in turn has contributed to production delays, the subsequent diversion of production for spare parts inventories to aircraft on assembly lines, and considerable use of interim contractor support, which may have some undetermined adverse effect on the early supportability of the system (at least during wartime).

- The maintenance of an indigenous U.S. production capability for the complete system has minimized serious schedule slippage caused by European production difficulties.

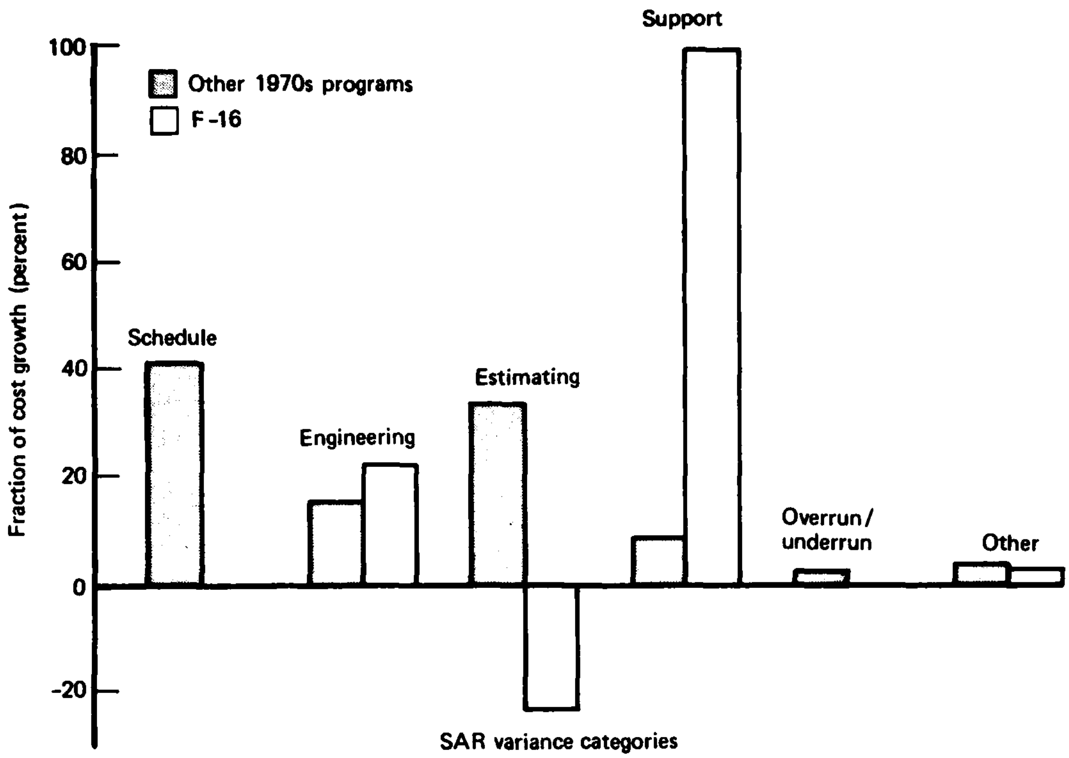


Fig. 43—Distribution of program cost growth, F-16 and other 1970s programs

Although experience with most European subcontractors has been positive, for various reasons some key airframe, engine, and avionics deliveries have lagged. The reservoir of U.S. production support has overcome these lags, preventing parts shortages from slowing U.S. and European final assembly lines. The flexibility to respond effectively to adversity distinguishes collaborative arrangements involving the United States from typical all-European programs, many of which have encountered considerable schedule slippage.

Cost Implications

- The adverse cost effect of coproduction on the U.S. Air Force F-16 program has been fairly small, while benefits external to the program seem potentially large.

Coproduction is expected to add about 5 percent to Air Force program costs for its first 650 F-16s. Disadvantageous currency fluctuations are expected to add at least another 1 percent or so to Air Force program costs. R&D recoupment charges from European program participants, returned to the U.S. Treasury, offset a substantial fraction, if not all, of these costs. Other benefits in the form of reductions in defense contractor overhead charges, cost savings in other programs (e.g., F-111, F-15) due to an increased production base, tax revenues from production for EPG air forces, and less quantifiable but militarily important NATO standardization benefits also offset or outweigh the apparent cost penalty.

- The net cost effect of the F-16 coproduction arrangement on the U.S. Air Force is the sum of some economies and some inefficiencies.

Increased production quantities have yielded savings in manufacturing labor, materials, and overhead expenses, while the duplication of effort entailed in subcontracting in Europe has added to program costs. These and other such factors that act to increase or reduce program costs are clearly a function of the particular coproduction arrangement adopted; hence, attempts to generalize about the specific cost effect of coproduction on the basis of just the F-16 program must be made cautiously.

- Coproduction has had a large effect on EPG program costs, but the Europeans have realized offsetting benefits.

The most plausible direct purchase option could have saved the EPG more than 30 percent in program costs compared with the costs of the present coproduction arrangement. Measured against this cost are substantial benefits to the Europeans deriving from technology transfer, employment stability, industry capitalization and depreciation, and military standardization, among others.

- The most tangible measure of EPG benefits, the program's industrial offset, is reasonably close to the goal set down in the MOU for the consortium as a whole, but it is not evenly distributed across the four participating countries.

The 52 percent industrial offset achieved thus far approaches the 58 percent objective called out in the MOU. In the individual countries, the offset varies from 72 to 33 percent. Although efforts are being made to rectify the imbalance, they are made more difficult by the lack of well-developed aerospace industries in the participating Scandinavian countries, and the situation seems to confirm the wisdom of making the offset guarantee to the consortium rather than to the individual countries.

- The F-16 program experience suggests that, in general, EPG contractors may not be price competitive across the board with U.S. aerospace contractors.

This observation pertains even after we correct for loadings and production runs of different quantities. Indeed, having EPG contractors produce disproportionate quantities of some items has been one technique used in the program to bring European subcontractor costs down to "reasonably competitive" levels. Lacking detailed knowledge of European contractor operations, we can only speculate about the reasons for their lack of competitiveness. Factors that may contribute include the requirement to produce an F-16 design optimized for U.S. production methods, the generally lower utilization rate of capital equipment and personnel in Europe, or the higher social costs carried as part of workers' salaries.

V. SUMMARY OF MAJOR FINDINGS

Coproduction is not a new acquisition approach, although corporate memory inside and outside the government about the means for efficiently and effectively using it on a multinational basis varies considerably. U.S. Air Force participation in the F-16 program, which features an unprecedented level of U.S.-European collaboration, has reintroduced many old questions and raised many new ones about the implications of entering into coproduction programs in the contemporary acquisition environment. Answers to many of these questions have not been immediately apparent to the Air Force, its contractors, OSD, or the Congress. Indeed, much of the debate about the implications of coproduction has been conducted on a rather narrow empirical base of experience with limited quantitative information. Recent coproduction experience within Europe and between the United States and European nations offers an opportunity to reassess the implications of coproduction in a contemporary setting, and in more quantitative terms than usual.

We must understand the implications of coproduction, particularly because higher national priorities may prevent the Air Force from being able to select or reject it. Accordingly, this report has attempted to illuminate the implications of multinational coproduction agreements and to identify various ways of maximizing their advantages and avoiding their pitfalls.

MAJOR FINDINGS

Collaborative programs involving the United States as a producer warrant considerably more optimism about outcomes than all-European collaborative ventures. Many of the differences between U.S. domestic program outcomes and European multinational program outcomes (e.g., program lengths) appear to be generic to European acquisition rather than a consequence of collaboration. The European aerospace acquisition setting, whether in a multinational or national context, is usually distinguished by a smaller scale of activities than U.S. programs, more restrictive workforce policies, more labor-intensive production approaches, a less competitive procurement environment, differences in scheduling tendencies, a less complex legal/regulatory setting, and less diverse military requirements.

The acquisition setting in the United States usually gives U.S. producers more options for dealing with program adversity, making it unlikely that problems found in collaborative or national European programs will occur as frequently or be as serious when the United States is involved. For example, workforce constraints can restrain the pace of a European program or its ability to recover schedule slippage regardless of collaboration. With U.S. involvement, a diverse production base that has greater freedom in changing labor inputs can shorten the time to achieve program goals or recover schedule slippage.

The usual U.S. policy of maintaining an indigenous U.S. production capability in collaborative ventures with Europe has provided extra insurance against large program delays that have plagued some European collaborative efforts not featuring extensive duplication. U.S. involvement can have a positive effect on program outcomes.

The United States can realize economic benefits, as well as other less quantifiable

but militarily important benefits, from appropriately structured coproduction programs. From a U.S. perspective, coproduction of a U.S. system will rarely be as favorable on a strictly economic basis as a direct sale to Europe. However, because our European allies are becoming less willing to accept the latter form of weapon transfer, the relevant basis for comparison is between the economics of a domestic program with no foreign sales to European nations and one that features foreign coproduction. There is no meaningful general formula to determine the cost consequences of coproduction arrangements, but one can estimate additional costs and savings for particular programs. In the F-16 program, the extra business generated as a consequence of European participation has offset most if not all of the cost penalties from subcontracting in Europe. The estimated incremental cost to the Air Force program of 4 to 5 percent is small compared with typical major weapon system acquisition cost growth from other sources.

Most accountings external to the program per se estimate net economic benefits derived from R&D recoupment charges, reductions in plant overheads, reductions in unit costs from extra production, and a host of other factors. Less quantifiable but militarily important advantages accrue to the United States from the adoption of a common aircraft system by several NATO countries.

Estimating the economic effect of the less frequent case of producing a European design in the United States is quite speculative, but such a strategy can involve sizable technical and programmatic risks. To estimate economic effects, one must measure some development cost avoidance against significant technology transfer efforts. These can include complicated and protracted license negotiations and technical data transfers, and consequential changes to adapt a system to meet worldwide U.S. commitments and make the system producible with the more capital-intensive U.S. manufacturing approach geared to a larger scale of production. Sizable testing efforts may also be required to demonstrate the success of the technology transfer. Transfers of this type thus far have found U.S. program participants either not anticipating or underestimating the extent of the technology transfer task, suggesting that this approach involves risks, although perhaps of a different character than those associated with indigenous development.

The effects of collaboration on cost growth have varied with the nature of the program. Many collaborative programs are structured within politically prescribed environments that contribute to inefficiencies, but excessive cost growth is not a necessary by-product. The multinational commitments made by all participating countries in the F-16 program contributed to a lack of delivery schedule, funding, or quantity changes that frequently contribute to cost growth. Indeed, the F-16's Selected Acquisition Report attributes no cost growth to schedule changes through late 1980. Its overall cost growth of 15 percent is about half the average for major programs of the 1970s at the same stage. The greater the amount of production integration between countries, the greater seems to be the pressure to live by the terms of original production schedules, diminishing one potential cause of cost growth.

By way of contrast, in the Roland program, unfamiliarity with weapon transfers from Europe brought about an inadequate appreciation of the technology transfer task and the level of design maturity, which, coupled with uneven government guidance during early phases of the program, led to poor cost estimates and major cost growth. Growth due to estimating errors was almost three times larger than in the average major weapon system acquisition program of the 1970s. Roland's overall cost growth is far greater than the average for major U.S. systems of the 1970s at the same stage. Clearly, the Roland program illustrates how collaboration can introduce complications that can increase costs.

From a European perspective, a policy of coproduction in lieu of direct purchases from the United States can entail considerable program cost penalties, but it can also provide some offsetting domestic benefits. Cost penalties can arise from a variety of factors including the loss of economies of scale on the U.S. production line, the cost of the technology transfer, the duplication of production operations in Europe, and the participation of noncompetitive European contractors. The last factor in particular makes it difficult to structure efficient coproduction programs. Contractors in the smaller European nations participating in the F-16 program were estimated to be cost-competitive on less than a third of the airframe and avionics items analyzed under the most favorable assumptions. (Most of the items were fairly inexpensive.) We estimated the original F-16 coproduction option to be 34 percent more costly to the EPG than a hypothetical direct purchase. Only European policymakers can weigh the cost penalty against potentially offsetting benefits such as the opportunity to produce aircraft to satisfy their nation's domestic needs as well as U.S. and third-country markets, stability in aerospace employment, technology transfer, industry modernization, and standardization of military equipment.

We expect, but have no definitive data to confirm, that the situation is somewhat different with the larger European nations. In contrast to the EPG countries, the greater scale and diversity of the aerospace production base in England, France, and Germany and the greater scale of equipment requirements in those nations might diminish cost penalties they could experience when coproducing with the United States rather than directly purchasing equipment from a U.S. manufacturer.

During the 1970s, large fluctuations in currency exchange rates and industrial prices complicated coproduction programs and could complicate future programs even more if these tendencies continue. Currency exchange rates are relevant to coproduction programs in three ways:

- —During the 1970s, exchange rates and industrial prices varied so as to increase prices in Europe relative to those in the United States. This has made it more difficult to find cost-competitive contractors in Europe, and if the trend continues this will be even more difficult in coming years.
- —Fluctuating currency exchange rates can upset plans to distribute work to participating countries according to procurement value or other formulas. This can require reallocations of production responsibilities to bring program shares into balance, which can make program management more complex, delay a program, and increase costs.
- —Fluctuating exchange rates can affect the program costs of various program participants in unpredictable ways, making cost estimation more difficult and possibly adding unexpectedly to program cost. Although there are methods to reduce price fluctuations due to changes in exchange rates, in general these means have not been adopted on coproduction programs. Recent policy initiatives encouraging the use of these methods have the potential of distributing the effects of currency fluctuations among program participants.

U.S.-European collaborative programs will not necessarily be characterized by excessive length and schedule slippage although scheduling tasks will probably be more complicated. Critics frequently assert that collaborative programs have a tendency both to take longer and to slip more than comparable national programs. Looking across many European programs, however, we found it difficult to distinguish between schedule

tendencies brought about by European acquisition practices in general and those brought about by the participation of additional countries in a program.

There are striking differences in the typical lengths of U.S. and European military aircraft programs, whether the European program is national or multinational, particularly between first flight and initial operational delivery. U.S. contractors use large labor inputs to make a rapid transition to production in a manner unlike European contractors, which operate under more restrictive workforce policies. Because this transition from development to production frequently occurs about when nations join to collaborate in production, U.S. and European collaborators have to develop arrangements that accommodate these considerable differences in scheduling tendencies.

Collaboration introduces schedule complications. Efforts to establish new program frameworks, to rationalize different configuration, standardization, and delivery requirements, to accommodate different acquisition approaches, to distribute production responsibilities, to integrate fabrication and assembly operations at various locations, and to reach decisions using multinational committees all can affect schedules. Moreover, the greater the number of participants, the more chances of something like a funding problem, work stoppage, currency fluctuation, or bankruptcy in one country disrupting a program.

These kinds of complications have not always translated into longer programs or major schedule changes or slippage in collaborative programs involving the United States (e.g., F-104G, F-16), although internal program schedule adjustments to accommodate different U.S.-European scheduling tendencies have at times led to development and production concurrency that adds to program risks.

Recent policies calling for more limited and flexible offset and compensatory coproduction agreements appear to be well founded. Industrial offsets have been one of the most contentious and frequently discussed issues in the F-16 program, with respect to both the overall level of production contracts placed in all EPG countries and the distribution of these contracts among the members of the consortium. Although not strictly bound by the MOU to place proportionate levels of production work in particular countries, program management has tried, with great effort, to do so. Program management is bound to meet offset goals for the consortium as a whole, although there is an escape clause allowing for offset work outside the program. Offset agreements calling for specific offset targets stated in percentage or money terms or specifying that offset work is all to be within the program are particularly burdensome when the collaboration is with smaller European countries that do not have fully developed aerospace industries. Using inexperienced producers to satisfy offset goals internal to a program can lead to increased subcontracting costs and programmatic risks.

Certain features of multinational collaborative programs have made it more difficult to adhere to U.S. acquisition management procedures. Decisionmakers have departed from DSARC program review and control procedures that encourage sequential decisionmaking, policies that encourage the use of competition, and those that specify the way mission element needs are identified and met. Broader considerations may justify less than strict adherence to policy guidelines, but decisionmakers should remain aware of the possible consequences of deviating from them. Development or production decisions made without the full benefit of information generated during development phases can increase technical risks. International program agreements that stipulate placement of work in specific geographic regions that feature little or no competition among potential suppliers can drive

up subcontracting costs. Early specification of hardware development responsibilities among nations may stifle competition among technical alternatives to satisfy generic mission needs.

The most ambitious U.S. effort at coproduction, the F-16 program, has thus far experienced favorable cost, schedule, and performance outcomes. It is too soon to gauge coproduction's effect on its operational supportability. The diverse and multifaceted objectives of the F-16 program participants make simple judgments about program success inappropriate. The F-16 program has come considerably closer to meeting cost, schedule, and performance goals specified in Selected Acquisition Reports than the average major weapon system acquisition program of the 1970s. In this instance, at least, the United States has used coproduction effectively, despite the abundant programmatic complexities. The full consequences of the coproduction-induced accelerated program pace from development through deployment on the supportability of the system in operations cannot yet be ascertained.

RECOMMENDATIONS

From a U.S. perspective in general and an Air Force perspective in particular, our examination of coproduction issues prompts some guidance regarding future collaborative programs.

Current policies that encourage the maintenance of a largely indigenous U.S. production capability in coproduction programs should not be substantially altered. Experience with most European subcontractors in the F-16 program has been positive, but some key deliveries have lagged. The reservoir of U.S. production support helped overcome the effects of long European lead times early in the program and has prevented production problems from slowing U.S. and European final assembly lines. More than a decade earlier, similar production assistance contributed to a generally satisfactory schedule outcome in the production of the F-104G in Europe. The flexibility to respond to adversity quickly and effectively distinguishes collaborative arrangements involving the United States from purely European ventures, a number of which have experienced considerable schedule slippage.

Duplication of fabrication and assembly responsibilities need not always add significant cost penalties to a program, providing compensating actions are taken. Those may include selecting second production facilities at locations having advantageous indirect cost charges and wage rates and purchasing materials on a centralized or coordinated basis to obtain volume discounts. Other actions can also exploit the advantages of the larger buy in a collaborative program, including negotiated R&D recoupments and distributing production so as to bring down the cost of less cost-competitive geographically dictated suppliers.

Government guidance to contractors with respect to program objectives, standardization goals, royalty payments, data rights, and third country sales policies is essential prior to the consummation of license agreements. Uneven or nonexistent government guidance in the early stages of the Roland program complicated the technology transfer and contributed to an underestimation of the effort involved for technology transfer, fabrication, and test. The government, including the Office of the Secretary of Defense and the Air Force, should insure that this is not repeated in future collaborative programs.

As F-16 subcontractors in Europe demonstrate their production capabilities, the Air Force should consider the direct purchase of selected European-produced items

for incorporation as government-furnished equipment to reduce the cost burden of loadings applied by U.S. contractors. Loadings typically add 35 to 40 percent to the cost of items produced by European subcontractors for U.S. contractors in the F-16 program. The direct purchase option, which removes the loading, carries with it both benefits and disadvantages. It can lower the cost to the government, but it can also increase the management burden on the Air Force. Initiatives in this area have already begun.

Although not bound by the F-16 MOU to do this, the United States may profit from the selective participation of European subcontractors in F-16 follow-on production. Continuing with the present coproduction arrangement for a follow-on buy of 738 aircraft for the U.S. Air Force would clearly cost more than a purely domestic purchase, but production quantity differences in the initial coproduction arrangement may give European subcontractors a cost advantage over U.S. producers for a small number of moderately priced part sets. A flexible contractor selection approach may yield modest dividends.

The Air Force should review the legal, regulatory, and policy solutions developed in recent collaborative programs to see how they have dealt with U.S. and European differences with respect to arms export policies, technology transfer restrictions, and weapon system acquisition practices. Although F-16 and Roland program participants have developed ad hoc solutions to many impediments to collaboration, frequently by the use of exceptions or waivers, they have had to live with the consequences of others. A systematic study is needed to determine which of these solutions, if any, should be institutionalized to facilitate future U.S.-European collaborative ventures.

The adequacy of existing and planned mechanisms (NATO and others) for tracking system replacement needs should be reassessed. Meeting the early delivery dates specified by European governments contributed to the sale of the F-16 but also effectively foreclosed the sequential development and production of some key subsystems. This schedule compression introduced significant elements of risk into the program. The need to accommodate different national delivery requirements is inevitable, but planners of future U.S. weapon system developments could profit from earlier consideration of the replacement needs of potential customers.

More study is needed of the implications of collaboration on the subsequent operational support of weapon systems in general and, more specifically, on support of U.S. Air Force F-16s based in Europe. The present study has emphasized the planning and execution of collaborative programs through the production phase without delving into operational support issues. One might profitably consider how multinational considerations introduced during development and production can influence the ultimate supportability of systems. Moreover, given the enormous costs involved in supporting modern weapon systems, further study of how support policies can take advantage of certain features of coproduction appears valuable. Is it economically and militarily advantageous for the Air Force to exploit European production bases and spares inventories to support coproduced aircraft based in Europe? Should the United States use European assembly lines as major overhaul facilities for Air Force aircraft? What complications are introduced if European and U.S. aircraft diverge in configuration in the future? Will this render certain types of European support impractical? F-16s will be based in Europe for many years to come at great expense. It may be appropriate to consider the efficacy of unconventional support arrangements made possible by the F-16's atypical production arrangement, perhaps paying off in enhanced aircraft availability or lower support costs.

EPILOGUE

Coproduction, like any weapon system acquisition strategy, cannot be considered uniformly advantageous to the Air Force. At the same time, the record does not suggest that it is as disadvantageous as many critics have asserted, particularly those who use the outcomes of a few purely European collaborative ventures to project outcomes of U.S.-European efforts. Its use will probably grow, despite some unfavorable trends, because the governments involved want it.

The Air Force should attempt to play an active role during the planning stages of these coproduction programs. Armed with experience garnered from the F-16 and other programs, it should press for arrangements that minimize some of the risks highlighted in this report and that maximize the economic and other benefits that can sometimes be achieved through coproduction. Through an active role the Air Force can preserve the decisionmaking authority it generally enjoys in domestic programs and it can do so with the knowledge that in the F-16 program, the most complicated example of U.S.-European collaboration yet attempted, it has thus far overcome most of the programmatic complications and achieved a generally favorable outcome.

Appendix A

U.S. FULL-SYSTEM COPRODUCTION PROGRAMS

This appendix contains a list of major system coproduction programs since World War II. It is based on an extensive literature search, but it may be incomplete. Included are the designation of the system, the type of system, the country or countries involved in the coproduction program, and the year the coproduction agreement was made or coproduction began. When a company produced several variants or improved versions of a system, as Augusta did for the UH-1 helicopter, these are all listed as a single coproduction agreement; but when a follow-on to a system involved major changes and the negotiation of a new coproduction agreement, as for the AIM-9L and the Improved Hawk programs, these are counted as separate instances of coproduction.[1]

System Designation	Type of System	Countries Involved	Coproduction Start[a]
Foreign Production of U.S.-Designed Systems			
AIM-4D (RB-2B)	Missile	Sweden	Not available
AIM-26B (RB-27)	Missile	Sweden	Not available
S-51	Helicopter	U.K.	1947
F-86	Fighter	Canada	1949
		Australia	1952
		Italy	1954
		Japan	1955
S-55	Helicopter	U.K.	1950
		Japan	1958
M-7	Howitzer	Canada	1950
T-33	Trainer	Canada	1951
		Japan	1954
47G	Helicopter	Italy	1952
		Japan	1953
		U.K.	1957
Mk.44	Torpedo	Italy	Late 1950s
		France	Late 1950s
		Canada	Late 1950s
T-34	Trainer	Canada	1955
		Japan	1957
		Argentina	1958
S-2 (CS2F-1)	Antisubmarine Warfare Aircraft	Canada	1955
S-58	Helicopter	U.K.	1956
		France	1960
P-2H	Antisubmarine Warfare Aircraft	Japan	1956

[a]This is generally the year that the coproduction agreement was signed.

[1]Clearly, there could be differences of opinion about when a follow-on is sufficiently different from the original to count as a new program, but only general conclusions are drawn about the extent of U.S. coproduction experience. Making these decisions differently would not have a significant effect on any of the conclusions.

System Designation	Type of System	Countries Involved	Coproduction Start[a]
F-104	*Fighter*	FRG (F-104G)	1959
Super		Belgium (F-104G)	1959
Starfighter		Canada (CF-104)	1959
		Netherlands (F-104G)	1960
		Japan (F-104J)	1960
		Italy (F-104G/S)	1961
SH-3	Helicopter	U.K.	1959
		Japan	1960
		Canada	1962
		Italy	1965
Hawk	Missile	France	1959
		Belgium	1959
		FRG	1959
		Italy	1959
		Netherlands	1959
AGM-12B	Missile	Norway	1960
S-62	Helicopter	Japan	1960
KV-107	Helicopter	Japan	1960
UH-1B/D	Helicopter	Italy	1961
(204B, 205, 206, 212)		Japan	1964
		Republic of China	1969
AIM-9B	Missile	Belgium	1962
NATO Sidewinder		FRG	1962
		Denmark	1962
		Greece	1962
		Netherlands	1962
		Norway	1962
		Portugal	1962
		Turkey	1962
KH-4	Helicopter	Japan	1962
S-61B	Helicopter	Canada	1962
		Japan	1962
		Italy	1963
		U.K.	1963
Bullpup	Missile	Denmark	1962
		Norway	1962
		Turkey	1962
		U.K.	1962
CH-46	Helicopter		
(107-2)		Japan	1963
F-5	Fighter	Canada	1965
		Spain	1965
		Republic of China	1973
		Switzerland	1976
		Republic of Korea	1979
M60-A1	Tank	Italy	1965
M-109	Howitzer	Netherlands	1966
		Norway	1966
		Italy	
M-113	APC	Italy	1967
		Belgium	1979
Nike Hercules	Missile	Japan	1967
OH-58	Helicopter	Italy	1967
		Australia	1971
AIM-7E Sparrow	Missile	Italy	1967
		Japan	1971
		U.K.	1973
CH-53	Helicopter	FRG	1968
(S-65A)			

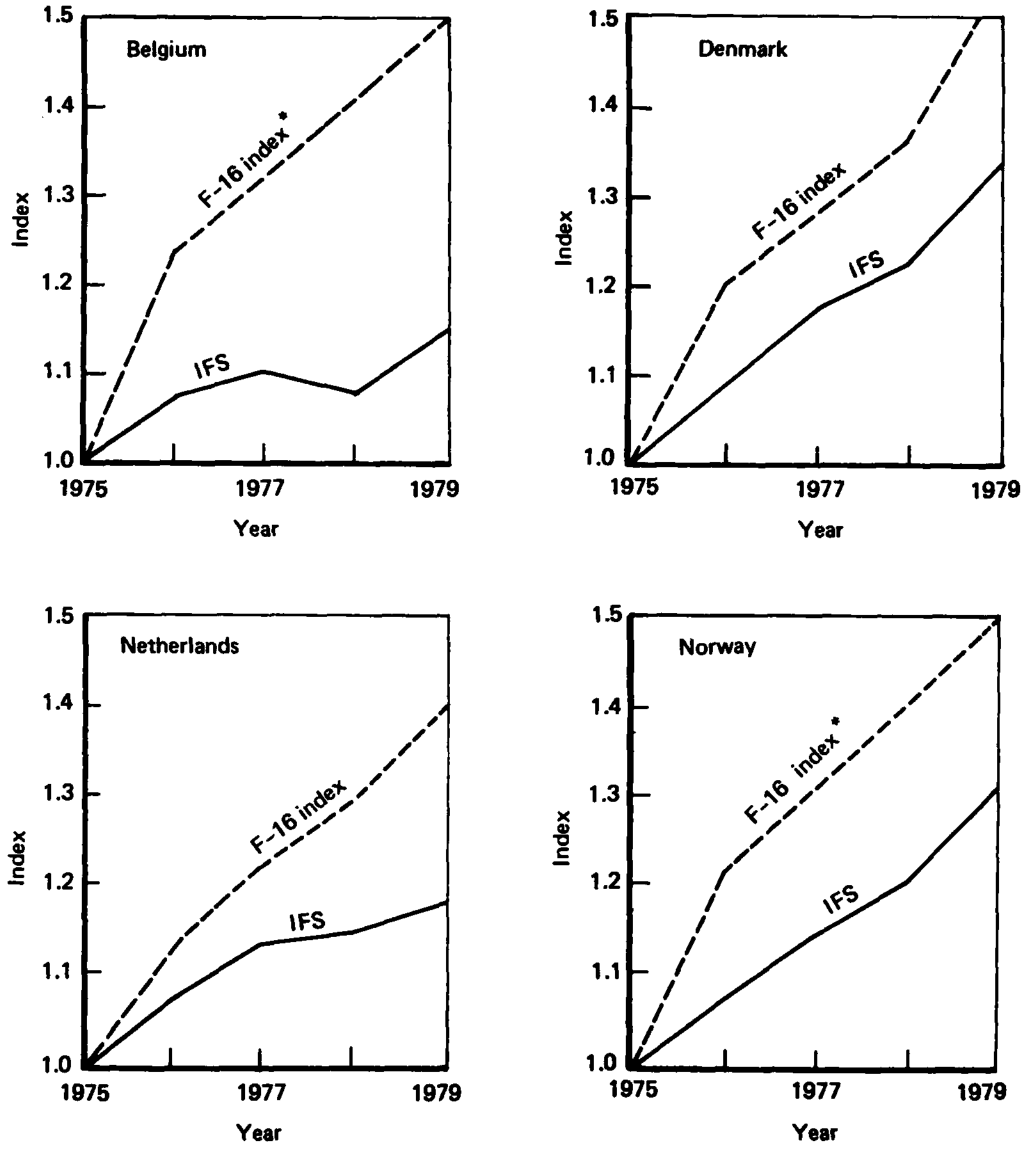
[a]This is generally the year that the coproduction agreement was signed.

System Designation	Type of System	Countries Involved	Coproduction Start[a]
OH-6	Helicopter	Japan	1968
		Italy	1969
		Argentina	1973
		Republic of Korea	1976
NATO Sea Sparrow	Missile	Denmark	1969
		Italy	1969
		Norway	1969
		Belgium	1970
		Netherlands	1970
		Canada	
CH-47 Chinook	Helicopter	Italy	1969
F-4	Fighter	U.K.	1969
		Japan	1969
MIM-23A/B Improved Hawk	Missile	Denmark	1974
		Italy	1974
		France	1974
		FRG	1974
		Netherlands	1974
		Belgium	1979
		Japan	1980
P-3C	Antisubmarine Warfare Aircraft	Japan	1978
F-15	Fighter	Japan	1978
AIM-9L Sidewinder	Missile	FRG	1978
		Italy	1978
		Norway	1978
		U.K.	1978
E-3A NATO AWACS	Aircraft	Belgium	1978
		Canada	1978
		Denmark	1978
		FRG	1978
		Greece	1978
		Italy	1978
		Netherlands	1978
		Norway	1978
		Turkey	1978
XM-2 (AIFV)	Armored Vehicle	Belgium	1979
214ST	Helicopter	Japan	1980
Copperhead	Projectile	Belgium	1980
		FRG	1980
		Italy	1980
		Netherlands	1980
		U.K.	1980
U.S. Licensed Production of Foreign-Designed Systems			
B-57 (Canberra)	Aircraft	U.K.	1951
Roland II	Missile System	FRG	1977
		France	1977
Fully-Integrated Coproduction			
F-16	Fighter	Netherlands	1975
		Belgium	1975
		Norway	1975
		Denmark	1975
AV-8B	V/STOL Fighter/ Attack Aircraft	U.K.	1981

[a]This is generally the year that the coproduction agreement was signed.

Appendix B

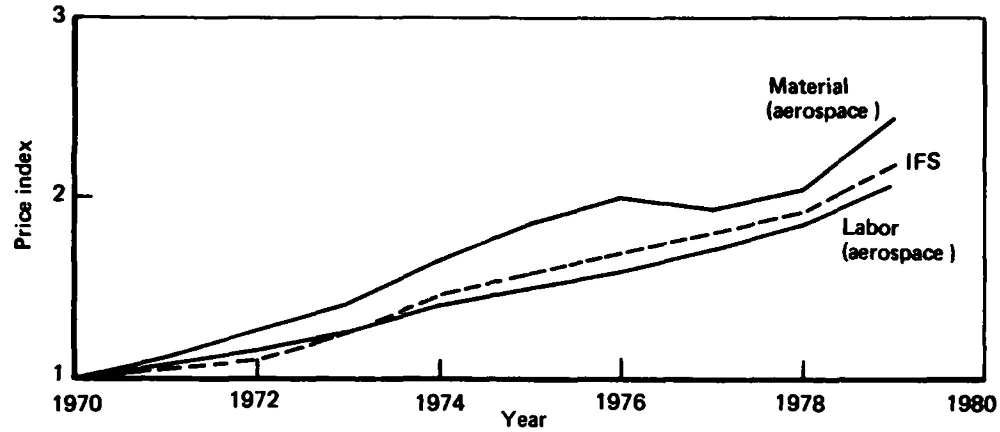
SELECTED U.S. AND EUROPEAN PRICE INDEXES



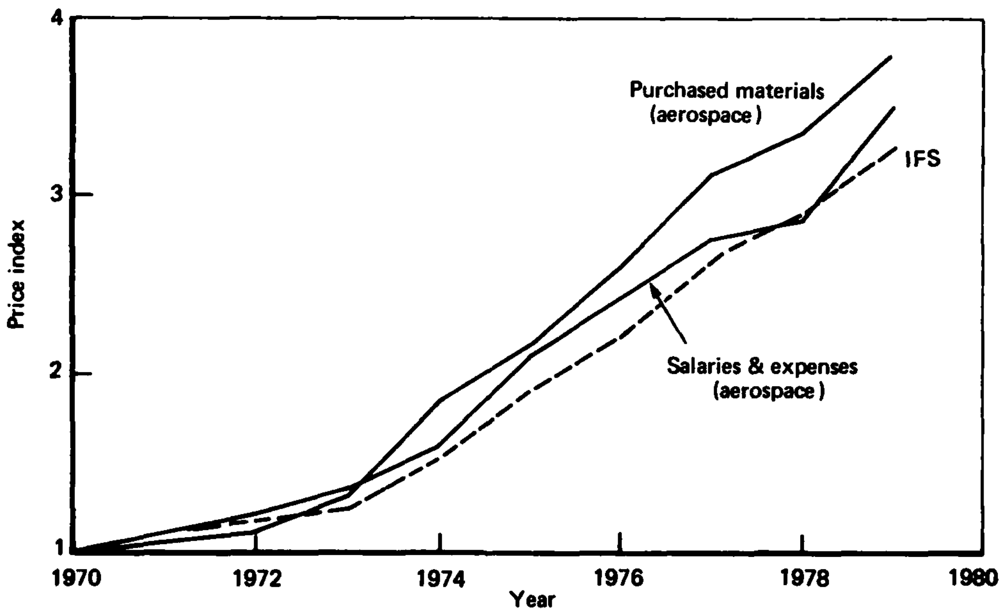
*Belgian and Norwegian indexes use U.S. material inflation as the material input to their F-16 index.

SOURCES: F-16 SPO; International Financial Statistics (IFS), October 1981, (Country Tables; line 63)

Fig. B.1—Aerospace and industrial price indexes—F-16 European participating countries



(a) U.S. Industrial Price Index and labor and material indexes of a major U.S. aerospace manufacturer



(b) U.K. Industrial Price Index and industry wide aerospace labor and materials indexes

SOURCES: International Financial Statistics (IFS), Country Tables, Index 63 (various years); proprietary data furnished to Rand by U.S. aerospace contractors; *British Business* (communications with Mr. Raymond Wilson, Business Manager).

Note: Content of indexes vary by country, see International Financial Statistics for definitions.

Fig. B.2—Aerospace and industrial price indexes—United States and United Kingdom

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